Leavenworth National Fish Hatchery
U.S. Fish and Wildlife Service
Annual Flow Monitoring Report
Water Year 2011

January 11, 2012

In accordance with

State of Washington
Department of Ecology
Water Quality Program

EPA CWA 401 Certification Order No. 7192
Specific Conditions Requirements
B.1.c.i. Flow Monitoring in the Historical and Hatchery Channels
B.1.c.ii. Flow Monitoring in Snow Lakes and Snow Creek
B.6.a.i. & ii. Water Use and Temperature in LNFH Operations

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INTRODUCTION

The Leavenworth National Fish Hatchery (LNFH) is located on Icicle Creek, a tributary to the Wenatchee River, at river mile (RM) 3.0 near Leavenworth, Washington. LNFH operates under the authority of the Rivers and Harbors Act of August 30, 1935 (49 Stat. 1028). The goal of the hatchery is to assist in the mitigation for fish production loss associated with the construction and operation of Grand Coulee Dam. Currently, LNFH's production goal is 1.2 million spring Chinook salmon. Also, LNFH supports the Yakama Nation's Coho Reintroduction Project by providing hatchery facilities for part of its expanded coho salmon production program. The LNFH's water delivery system consists of five major components and conveyance systems: (1) intake and pipeline; (2) the Snow/Nada Lake Basin supplementation water supply reservoirs; (3) the well system on LNFH property; 4) water discharge facilities; and 5) structures 2 and 5.

In January 2008, the U.S. Fish and Wildlife Service (Service) requested a Clean Water Act (CWA) Section 401 Certification from the Washington State Department of Ecology (Ecology) for a 2005 U.S. Environmental Protection Agency (EPA) National Pollution Discharge Elimination System (NPDES) permit application for the LNFH. Ecology issued a CWA Section 401 Certification Order 7192 (Order) in January 2010. The terms of the Order require a continuous monitoring plan and annual reporting for Snow Lakes and Snow Creek (Order section B.1.c.ii.) and the hatchery channel and historical channel (Order section B.1.c.i.). The Service submitted monitoring plans to Ecology in April 2010 and Ecology approved in September 2010. In addition, the terms of the Order (section B.6.a.i. & ii.) require continuous monitoring and annual reporting of flow from groundwater and surface water inputs to the LNFH, discharges from the LNFH to Icicle Creek, and comparison of temperature from flow inputs to the flow outputs by using a flow-weighted averaging technique. This report provides the monitoring results required by the Order, the first monitoring report produced by the Service under Order 7192.

LNFH submitted a new NPDES permit application to the EPA on October 24, 2011 as substantial changes to hatchery operations have occurred since 2005. On October 26, 2011, LNFH requested a new CWA Section 401 Certification from Ecology to be associated with the new NPDES application. Currently, LNFH is fulfilling the requirements of the January 2010 Order 7192 until a new CWA Section 401 Certification Order is developed.

SITE DESCRIPTIONS AND MEASUREMENT METHODS

To quantify the amount of water flowing in the historical channel and hatchery channel of Icicle Creek, the Service proposed initiating surface water monitoring at two locations on the LNFH's property (Table 1, Figure 1); Historical Channel at Structure 2 and Hatchery Channel at Spillway. To quantify the amount of water released from Snow Lake into Icicle Creek, the Service proposed initiating surface water monitoring at two locations in the Snow Creek drainage (Table 1, Figure 2); Snow Lakes Outlet and Snow Creek Mouth. Once Ecology accepted the proposals, the Service implemented the monitoring plans as soon as possible. To quantify the amount of water and temperature of water input and output from the LNFH, the Service implemented monitoring at seven production well sites, one site for inflow, and two sites for outflow from the LNFH. The production well sites are Production Well No. 1 - 7 (PW-1-7), the LNFH inflow site is LNFH Icicle Creek Diversion, and the LNFH outflow sites are LNFH Discharge at Fish Ladder (Outfall 1) and LNFH Discharge at Abatement Pond (Outfall 2).

Table 1. List of site numbers, names, parameters, measuring device, and data inventory.

Site Number	Site Name	Parameter	Measuring Device	Continuous Data Inventory for Water Year 2011
322501	*LNFH Discharge at Fish Ladder (Outfall 1)*			
		gage height	ultrasonic level transducer	Oct 1 - Sep 30
		discharge	artificial control - flume	Oct 1 - Sep 30
		water temperature	thermistor	Oct 1 - Sep 30
322502	*LNFH Discharge at Abatement Pond (Outfall 2)*			
		gage height	staff gage	Jul 21 - Sep 30
		discharge	artificial control - weir	Jul 21 - Sep 30
		water temperature	thermistor	Oct 1 - Sep 30
322503	*Snow Creek at Mouth*			
		gage height	float and shaft encoder	Oct 1 - Sep 30
		discharge	artificial control - weir	Oct 1 - Sep 30
322506	*Snow Lake Outlet*			
		volume	calculated	Oct 1 - Sep 30
		discharge	artificial control - pipe valve	Oct 1 - Sep 30
		gage height	pressure transducer	Oct 1 - Sep 30
322508	*Production Well No. 1 (PW-1)*			
		well level	pressure transducer	Feb 1 - Sep 30
		well discharge	In-line meter	Feb 1 - Sep 30
		water temperature	thermistor	Feb 1 - Sep 30
322517	*Production Well No. 2 (PW-2)*			
		well level	pressure transducer	Oct 1 - Sep 30
		well discharge	In-line meter	Oct 1 - Sep 30
		water temperature	thermistor	Dec 15 - Sep 30
322510	*Production Well No. 3 (PW-3)*			
		well level	pressure transducer	Oct 1 - Sep 30
		well discharge	In-line meter	Oct 1 - Sep 30
		water temperature	thermistor	Dec 15 - Sep 30
322511	*Production Well No. 4 (PW-4)*			
		well level	pressure transducer	Oct 1 - Sep 30
		well discharge	In-line meter	Oct 1 - Sep 30
		water temperature	thermistor	Dec 15 - Sep 30
322512	*Production Well No. 5 (PW-5)*			
		well level	pressure transducer	Oct 1 - Sep 30
		well discharge	In-line meter	Oct 1 - Sep 30
		water temperature	thermistor	Dec 15 - Sep 30
322513	*Production Well No. 6 (PW-6)*			

		well level	pressure transducer	Oct 1 - Sep 30
		well discharge	In-line meter	Oct 1 - Sep 30
		water temperature	thermistor	Dec 15 - Sep 30
322514	*Production Well No. 7 (PW-7)*			
		well level	pressure transducer	Oct 1 - Sep 30
		well discharge	In-line meter	Feb 19- Sep 30
		water temperature	thermistor	Dec 15 - Sep 30
322525	*Historical Channel at Structure 2*			
		gage height	pressure transducer/bubble gage	Oct 1 - Sep 30
		discharge	artificial control	Oct 1 - Sep 30
322527	*Hatchery Channel at Spillway*			
		gage height	bubble gage	May 10 - Sep 30
		discharge	artificial control - weir	May 10 - Sep 30
322533	*LNFH Icicle Creek Diversion*			
		water temperature	thermistor	Oct 1 - Sep 30*
		discharge	acoustic Doppler current profiler	Apr 5 - Sep 30

*Data for LNFH Icicle Cr Diversion is missing between June 11, 2011 and September 27, 2011 due to thermistor malfunction.

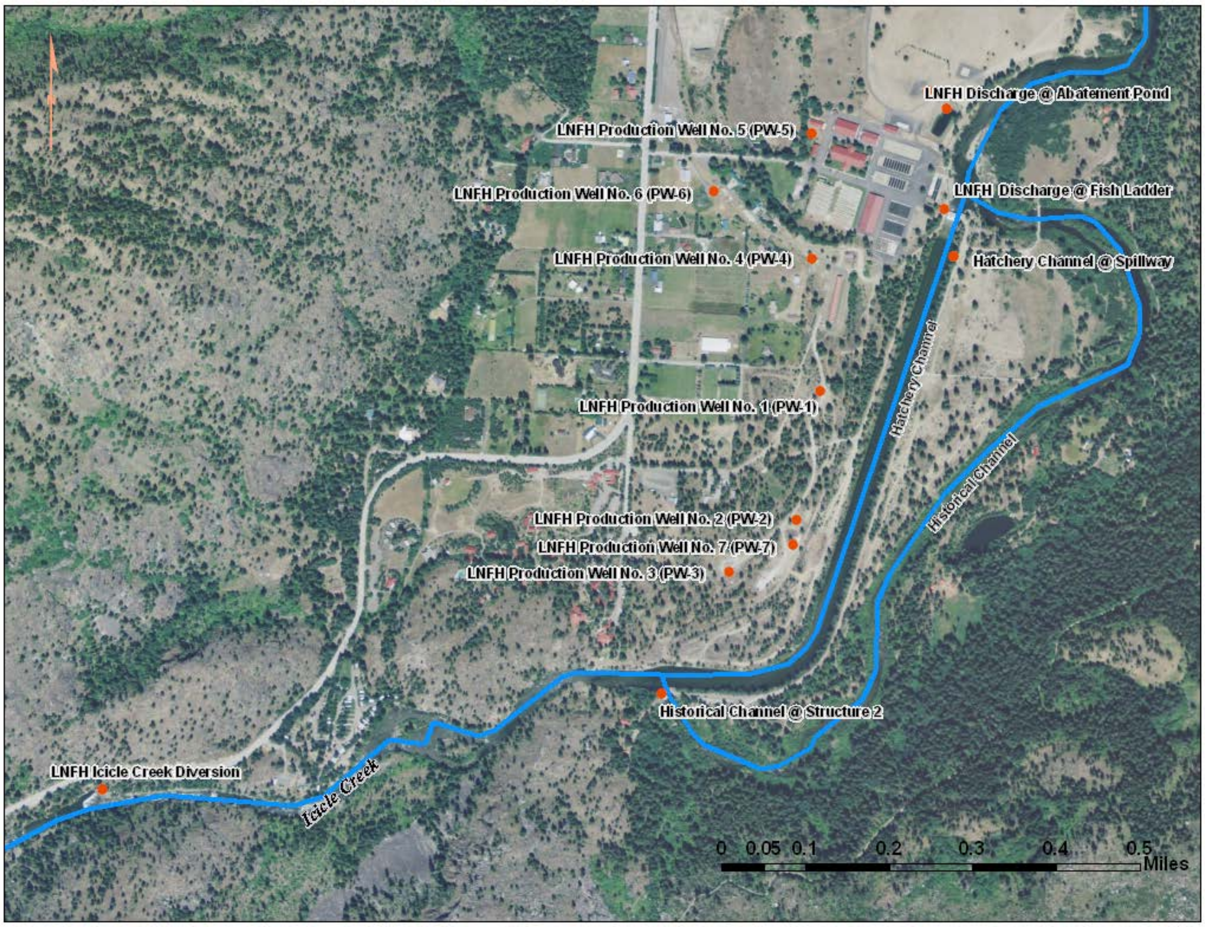

Figure 1. A map of water measurement sites near the LNFH. Orange dots denote the location of the measurement instrumentation.

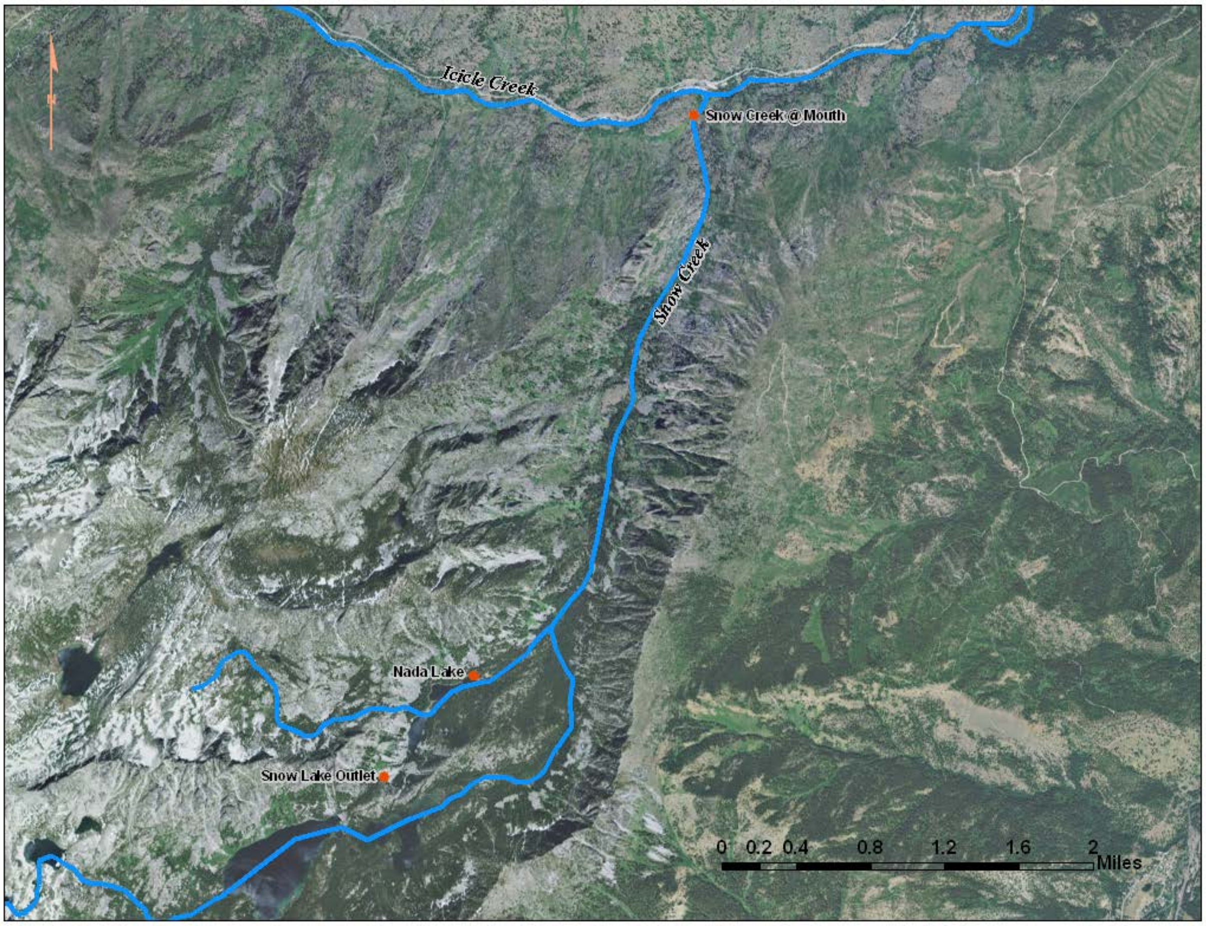

Figure 2. A map Snow Lakes and Snow Creek water measurement sites. Orange dots denote the location of the measurement instrumentation.

Historical Channel and Hatchery Channel

Historical Channel at Structure 2

A double radial gate (Structure 2) at the upstream end of the historical channel controls flow distribution between the historical channel and hatchery channel. Sverdrup (2000) identified the equations for estimating discharge in the radial gate through a hydrologic and hydraulic analysis of the historical channel (Equation 1).

Equation 1. $$Q = C * W * H^{1.5}$$

Where: Q = discharge in cubic feet per second (cfs)*

W= width of the radial gate opening (16 feet)

H = height of the water surface above base of the Structure 2 (feet)

C = weir coefficient (2.8)

* Equation 1 applies to one of the structure's gates. To determine flow through both gates multiply Equation 1 by two.

Equation 1 is only applicable when both radial gates are open and not in contact with the water surface. Measurements in the historical channel downstream of Structure 2 confirm that Equation 1 provides a good estimate of flow through the structure (Table 2).

Table 2. Estimated and measured flow in the historical channel using Equation 1 when structure 2 gates are not in contact water surface.

Date	Height of Water (feet)	Estimated flow (cfs)	Measured flow (cfs)	Percent Difference
9/30/09	0.70	52	52.6	+1%
10/15/09	1.06	98	101	+3%

When Structure 2 is adjusted, the two radial gates are lowered simultaneously towards the base of the structure. The gates are set so both are lowered the same distance when adjustments are made. In these conditions the following equation (2) (Sverdrup 2000) is used to estimate flow through Structure 2.

Equation 2. $$Q = B*C*W*\sqrt{(2*g)*H}$$

Where: Q = discharge in cubic feet per second (cfs)*

B = size of the opening under the radial gate (feet)

H = height of water surface above the base of Structure 2 (feet)

C = coefficient of discharge determined empirically from measurements (0.5).

W = width of the radial gate opening (16 feet).

g = acceleration due to gravity (32.2 ft/s^2)

* Equation 2 applies to one of the structure's gates. To determine flow through both gates multiply Equation 2 by two.

Point measurements of discharge downstream of Structure 2 indicates Equation 2 is an effective measure of flow into the historical channel when the gates are partially open (Table 3).

Table 3. Estimated and measured flow in the historical channel using Equation 2 with gates at Structure 2 partially open.

Date	Opening (ft)	Height of Water (ft)	Estimated Flow (cfs)	Measured Flow (cfs)	Percent Difference
9/30/09	0.30	1.90	53	52	-2%
10/1/09	0.30	2.00	54	52	-4%
10/8/09	0.06	5.23	18	17.6	-2%
10/9/09	0.16	3.75	40	38	-5%
10/14/09	0.46	0.69	49	46	-6%

A wire weight gage mounted on the fence railing of Structure 2 measures the height of water above the Structure 2 spillway (Figure 3). The gage was set so that 0.0 feet equates to the top of the Structure 2 spillway crest. The maximum opening of the radial gate is 5 feet and limits the use of Equation 1 to water heights of 5 feet or less over the spillway crest. Measurements using this gage that were applied to Equations 1 or 2 to quantify flow into the historical channel. The wire weight gage is located approximately 20 feet upstream of the spillway crest of Structure 2.

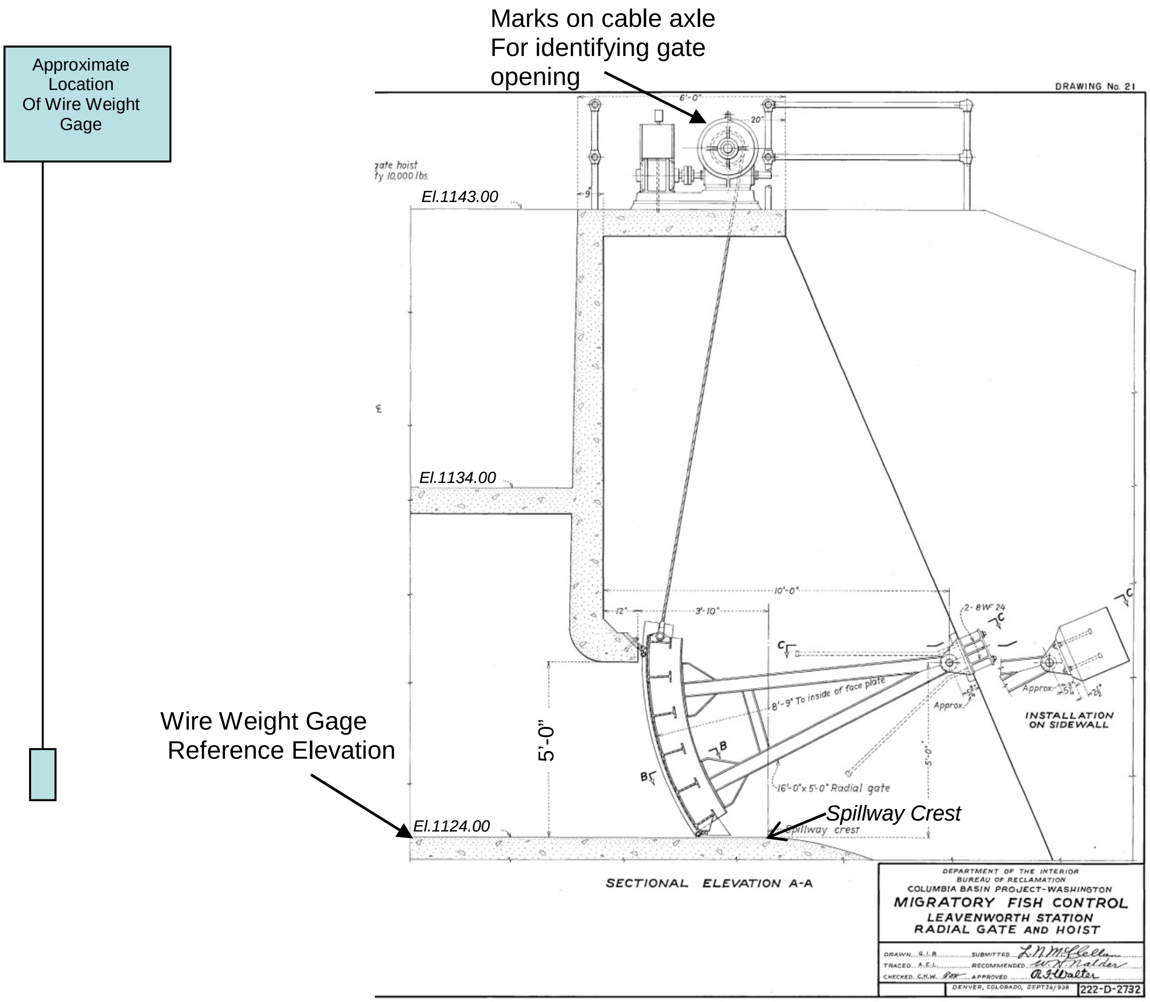

Figure 3. Cross section view of Structure 2 radial gate with approximate measurement locations. Location and size of wire weight gage not to scale.

To monitor water levels at the radial gate continuously, the Service mounted a 15 psi pressure transducer inside the pump well; a well inside the upstream bulkhead wall of Structure 2 that connects to the creek at the site of the wire weight gage. Beginning October 5, 2010, water levels recorded by the pressure transducer referenced the wire-weight gage. A bubbler system (non-submersible pressure transducer) replaced the pressure transducer on September 20, 2011. The datalogger recorded water levels at hourly intervals during the winter and 15-minute intervals in the summer. The datalogger was not set to record 15-minute intervals during the winter as originally described in the monitoring proposal to reduce the amount of battery power needed for higher interval measurements in the event the site was not accessible.

The radial gate opening was 4.74 feet throughout the entire water year of 2011. The radial gate did not submerge until the water levels measured at the wire weight were 7.6 feet and higher. Five check measurements were completed with either the SonTek FlowTracker Handheld Acoustic Doppler Velocimeter (FlowTracker ADV) or the SonTek RiverSurveyor Acoustic Doppler Current Profiler (RiverSurveyor ADCP). The highest check flow measurement was 7.08 feet (1680 cfs) and flows calculated above this stage are estimated.

Hatchery Channel at Spillway

Water backs up and fills the hatchery channel under two conditions; 1) when natural stream flows are high enough to back-up at structure 2 and flow down the hatchery channel or 2) the gates at structure 2 are lowered to direct flow down the hatchery channel. The elevation of the water surface in the hatchery channel was referenced to a staff gage mounted on the upstream edge of the spillway. Flow out of the hatchery channel was estimated using the following equation (3). Equation 3 was developed using the Bureau of Reclamation's WinFlume software (version 1.05.0029).

Equation 3. $$Q = 274.4 * H^{1.587}$$

Where: Q = estimated discharge over the channel spillway (cfs)

H = height of water over the channel spillway

The original staff gage was installed in September 2009 (figure 4). The original staff gage elevation of 0.0 feet is equivalent to the top of the spillway. On September 20, 2011 a new staff gage was installed in the hatchery channel approximately 120 feet upstream of the spillway, in order to avoid drawdown effects near the spillway. The original staff gage offsets the new staff gage by 2.99 feet; where the original staff plate is 0 feet at the 2.99 feet mark on the newly installed staff plate. A bubbler gage was installed May 10, 2011 to record water levels at 15 minute intervals. When the water levels reached the spillway crest on May 11, 2011 the bubbler gage was assigned to 0 feet to concur with the original staff plate reading of 0 feet. No other recording gage checks were made to check against the original staff plate due to its inaccessibility during high flows and the lack of staff gage to reference water heights below the elevation of the spillway. Due to the lack of stage data checks, stage and discharge are considered estimated for water year 2011. After the installation of the new staff plate and an offset of 2.99 feet were determined, the recorded stage data was shifted down 2.99 feet. Six check measurements plot -0.1 feet from the rating curve created with Equation 3. Equation 3 was replaced by a new rating curve, which incorporated the six check measurements and the new staff plate offset.

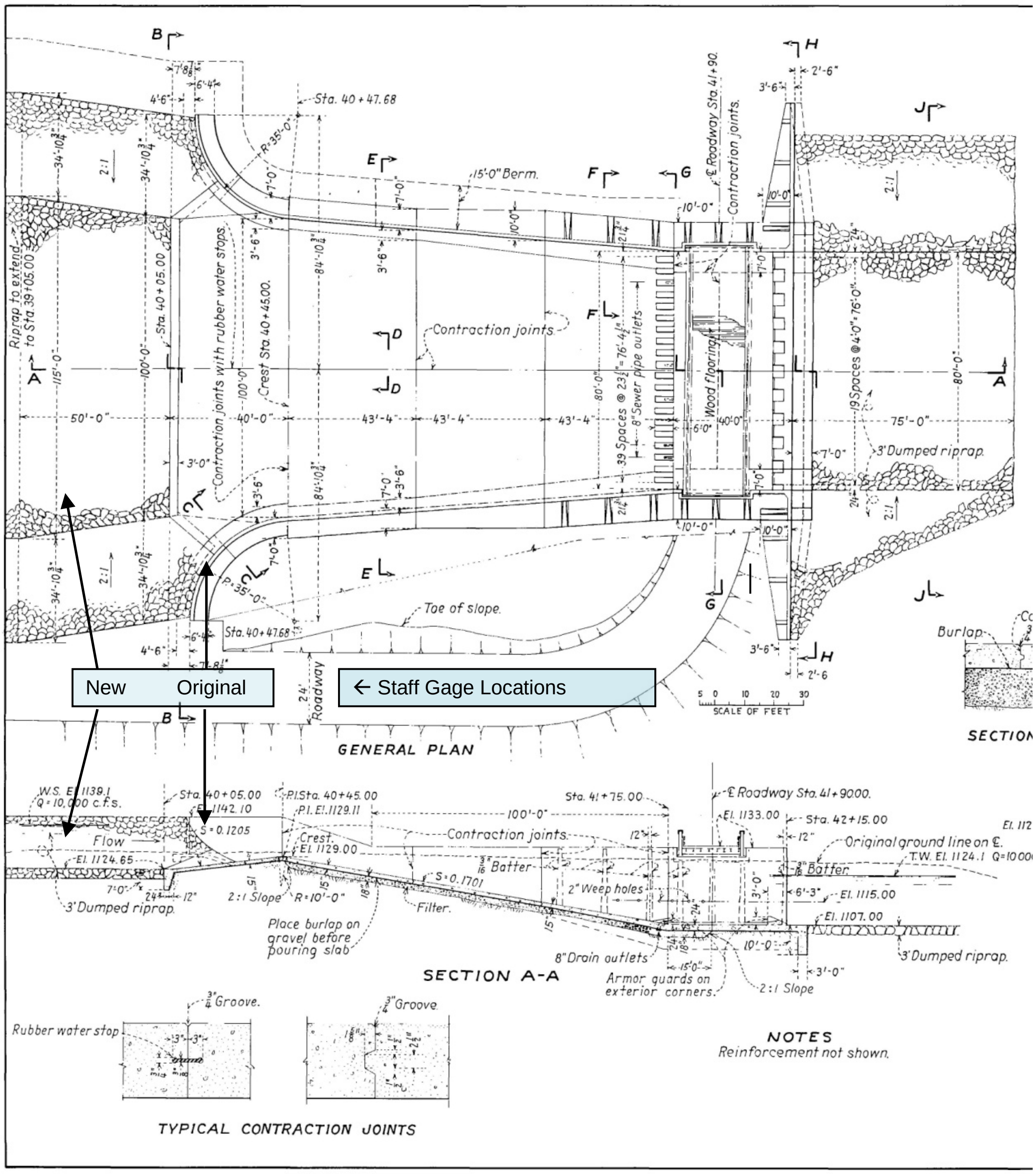

Figure 4. The figure shows the approximate location of staff gage for measuring height of water above the Hatchery Channel at Spillway. A plan view of the spillway is shown in the top part of the figure and the cross-section (A-A, identified in the plan view) is shown in the bottom of the figure. This is from the original Bureau of Reclamation drawings of the spillway.

Snow Lakes and Snow Creek

Snow Lake Outlet

Water in Upper Snow Lake is artificially released to Snow Creek through outlet works constructed by the Bureau of Reclamation in the 1940s. The Bureau of Reclamation built the outlet works by blasting a tunnel into granite underneath the lake, installed a 30” pipeline and fitted it with a 20” butterfly valve that releases water from Upper Snow Lake. Water from the lake flows down a talus slope into Nada Lake, enters Snow Creek and eventually flows into Icicle Creek. LNFH personnel release water from Upper Snow Lake to supplement Icicle Creek during the low flow period between mid-July and October 1st of each year. LNFH personnel open and adjust the valve manually. Flow through the 20” butterfly valve is calculated using the following equation:

Equation 4. $$Q = (\frac{C_q}{0.0751}) * \sqrt{H}$$

Where: Q = Discharge from the outlet valve (cfs)

C_q = Coefficient based on the valve opening

H = Height of water recorded by pressure transducer gage in outlet tunnel (gage position (ft) + 11.3). 11.3 is the elevation difference between the pressure transducer and the 20” outlet valve.

The height of water above the 20” butterfly valve is measured using a 100 psi pressure transducer mounted on the 30” delivery pipeline. The pressure transducer output, in pounds per square inch (psi), is converted to feet by multiplying by 2.3703. A datalogger records pressure transducer heights at 4 hour intervals. The size of the butterfly valve opening is marked on its valve stem with 3 points; 0, 45, and 90 degrees. LNFH personnel record the pressure transducer, pressure gage and valve openings during visits to the outlet tunnel 3-6 times per year. This data was used to calculate mean daily water levels, releases, and storage volume at Upper Snow Lake for each day of the year.

The butterfly valve stem is insufficiently marked to set the valve to an exact opening except at the 3 marks previously listed. To determine valve opening at other angles LNFH personnel have gained experience in best approximating the valve stem opening that corresponds with the desired flow out of Snow Lakes. Estimated releases were checked by measuring flow through a modified Parshall flume at the outlet of Nada Lake.

Additionally, total estimated releases are checked against the observed change in Snow Lake volume, determined using a capacity curve developed by the Bureau of Reclamation in 1939 (Figure 5), at the end of the release season. The Service has used Equation 4 since water year 2004 and found that the results show that it is a good measure of releases from the lake.

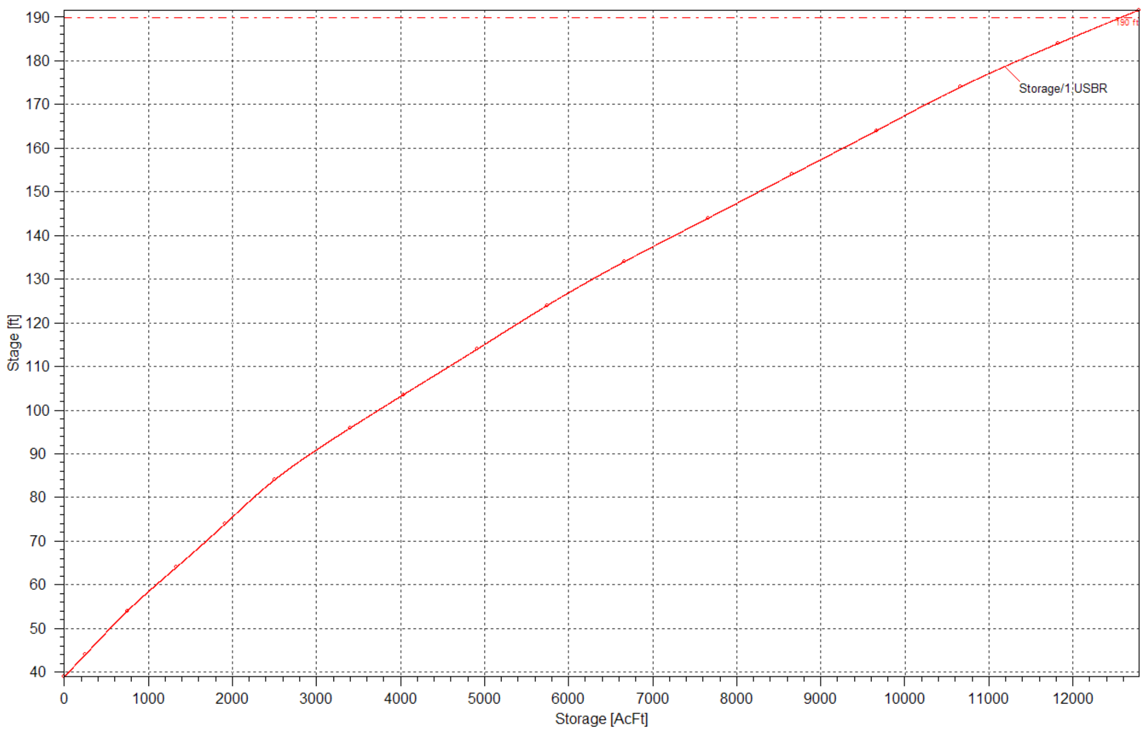

Figure 5. Volume of water stored in Upper Snow Lake vs. height of the lake's water surface above the tunnel's pressure gage.

Snow Creek Mouth Site

The Service has maintained a stream gaging station 600 feet upstream of the mouth of Snow Creek since 1997. The site measures releases and natural outflow from Nada Lake and Snow Lake as well as any additional flow from tributaries feeding Snow Creek upstream of the site. A combination broad-crested/v-notch cement weir spans the creek channel and provides control for measurement. The Service has developed a rating equation to calculate stream flow at the site. Flow measured at this site quantifies the amount of water entering Icicle Creek from Snow Creek and verifies flow released from Snow Lake. Wading measurements were made 5-10 feet upstream of the combination weir using a Price AA or SonTek Flowtracker current meter.

The site is equipped with a stilling well, a pulley/float shaft encoder, and datalogger for recording hourly water levels above the combination weir. The site was visited every 8-10 weeks during water year 2011 to make check discharge measurements and to download data.

Inflows and Outflows from the LNFH

LNFH Icicle Creek Diversion

The surface water intake facility is located approximately 1 mile upstream of Structure 2 on Icicle Creek and contains several components. The intake system is gravity-fed and relies on a low rubble masonry diversion dam with a concrete spillway crest across Icicle Creek at RM 4.5. The dam raises water elevations several feet allowing a portion of the flow to be diverted through a grizzly rack (bars spaced at about 6 inches) and into a concrete water conveyance channel. In the late 1980's, the Service reconstructed the diversion dam with a pool and weir fish ladder. Water which enters the conveyance channel is transported a short distance to a small building which houses a second finer rack (1 ½ inch bar spacing), an overflow spill section, and a sediment sluicing section. From this point, most of the water is conveyed to the LNFH through a 33-inch diameter buried pipeline and a small portion spills back to the creek downstream of the building. A gate valve, which remains open, regulates flow into the buried pipe. Approximately 1,260 feet down gradient from the beginning of the pipe system is a gate valve that controls flow into the delivery system for Cascade Orchard Irrigation District (COID). Cascade has a 1905 water right for 12.4 cubic feet per second (cfs) during the irrigation season (approximately May 1st through October 1st) and LNFH holds a 1942 water right to divert 42 cfs all year long.

A side-looking acoustic Doppler velocity meter (ADVM) was installed on the south side of the conveyance channel along the concrete wall to measure flow diverted from Icicle Creek. The flow measured by the ADVM includes the flows conveyed to the LNFH, the return flow from the overflow spill section in the house, the flows diverted to COID, the return flow from the overflow spill section at the pipeline diversion for COID, flows overbanking the diversion channel during high flows from Icicle Creek, and potential unknown leaks from the pipeline itself. The flows downstream of the ADVM and before the LNFH are not measured and therefore the LNFH intake is calculated based on the assumption of flow amounts to each of the diversions after the ADVM and before the LNFH. Estimated flows diverted after the ADVM and before the LNFH range between 0 and 15 cfs during the summer months and low Icicle Creek flows, and between 15 and 60 cfs during high Icicle Creek flows.

The ADVM uses acoustic Doppler technology to measure water velocity which is multiplied by the area of the channel to calculate discharge. The channel profile or area is determined from each stage level and is checked regularly. The ADVM velocity data is checked using an Index Velocity method (Ruhl and Simpson, 2005) used by the USGS.

Production Wells 1-7

Groundwater provides a smaller component of Leavenworth NFH's water delivery system. The Leavenworth NFH operates seven wells, which produce the quality of water needed to sustain the current fish production program. The wells are located on the west bank of the hatchery channel and withdraw water from two aquifers, one deep and one shallow. Well 5 draws from the deeper aquifer, which is not influenced locally by surface water. Wells 1-4 and 7 withdraw water from the shallow aquifer. Well 6 draws water from both aquifers. Recharge of the shallow aquifer is affected by how much flow is present, and thus percolates into groundwater, in the historical and hatchery channels. The water levels in wells 1- 4 and 7 rise when water is in the hatchery channel and fall when water is not present in the hatchery channel. Well water is used to supplement surface water to meet fish production temperature tolerances. Production wells are outfitted with inline flow meters, pressure transducers, and thermistors to measure well discharge, well level, and water temperature, respectively. Record of temperature was not available for any of the production wells until December 14, 2010. Well discharge and temperature data was not available for Production Well 7 until February 10, 2011.

LNFH Discharge at Fish Ladder (Outfall 1)

All of the surface water and groundwater used at the LNFH, minus any leakage or evaporation, is returned to Icicle Creek immediately downstream of the LNFH. This water is discharged into Icicle Creek at two locations, immediately downstream of the hatchery channel spillway at the base of a fish ladder (RM 2.8) or through the pollution abatement pond (RM 2.7). The return flow, which varies seasonally from 42-60 cfs, is combined with the outfall from a 30 inch pipe before flowing through a 3-foot concrete Parshall Flume. Greater than 98 percent of the water is returned to Icicle Creek through the Parshall Flume except when the rearing units are cleaned, a larger portion is retuned through the Pollution Abatement Pond. Recording equipment includes a Siemens ultrasonic water level sensor and is housed in a wooden shelter mounted on the stilling well connected to the flume. The equipment was in operation throughout water year 2011. The water levels from the Siemens sensor are used to calculate discharge using a theoretical equation. Data is stored immediately at the LNFH computer system. Potential problems with this site are two-fold. One problem is the flume is too closely connected to the Icicle Creek such that when Icicle Creek flow increases, the flume is submerged and flow is overestimated. . This problem could be alleviated by utilizing the second stilling well that currently exists at the flume to measures downstream water levels during submergence. The second stilling well is currently disconnected from the flume due to blockage in the connection between the stilling well and the flume. Efforts were made to remove the blockage although a connection was not reestablished. Additionally, only one parameter can be stored in the LNFH computer system and currently it is the calculated discharge value. The water levels recorded in the stilling well need to be recorded as well in order to check the measurements of the ultrasonic water level sensor.

LNFH Discharge at Abatement Pond (Outfall 2)

The second LNFH water discharge into Icicle Creek is through one of the two pollution abatement ponds (RM 2.7). Continual overflow from routine operations and daily cleaning effluent is routed through the pollution abatement pond. At least one section of the rearing units is cleaned nearly every day releasing approximately 4 cfs to Icicle Creek during the 2-hour cleaning period. The sand settling basin has an overflow bypass pipe which also empties into the Pollution Abatement Pond. The Pollution Abatement Pond discharges approximately 1 cfs (daily average) or less than two percent of the total effluent discharge for the LNFH. The outflow of the pollution abatement ponds was adapted with a 90 degree V-notch weir. A shaft encoder and datalogger were installed on July 21, 2011 and discharge through the weir is monitored continuously.

Temperature

Temperature was measured at all flow contributions and releases to and from the LNFH. Surface water temperatures around the LNFH are monitored with HOBO temperature loggers at three locations: LNFH Icicle Creek Diversion, LNFH Discharge at Fish Ladder (Outfall 1), and LNFH at Abatement Pond (Outfall 2). For quality assurance purposes, the HOBO temperature loggers were tested in two temperature baths representing the extremes of their monitoring conditions. The baths were made in coolers and had either an aquarium powerhead or air pump/stone added to mix the water and ensure a uniform temperature. One bath was maintained at room temperature (approximately 21degrees Celsius, 69.8 degrees Fahrenheit) and the second bath was maintained close to freezing (0 degrees Celsius, 32 degrees Fahrenheit), using cold tap water and 10 ice cube trays of ice. A lid was placed over this second cooler, except for a 1-inch opening to allow access for the thermometers. Temperatures were allowed to stabilize in both baths for ½ to 1 hour and the loggers were acclimated to the baths for at least 1/2 hour before temperature testing began. Water temperatures in the baths were recorded at 5-minute intervals by a National Institutes of Standard Technology (NIST) certified thermometer, a YSI temperature logger and the HOBO loggers.

After the calibration tests were concluded, the data was downloaded to HOBO software and exported to Excel for comparison with the NIST reference thermometer. If the mean absolute value of the difference was greater than 0.2 degrees Celsius (+/- 0.36 degrees Fahrenheit) the thermometers were tested again. If the mean difference was still more than +/- 0.2 degrees Celsius (+/- 0.36 degrees Fahrenheit) they were not used in the sampling.

In 2011, temperature thermistors used in the production wells were not checked due to the inability to remove and check the thermistors with a NIST thermometer in the same bath water. In the future, temperature checks will be attempted by quickly measuring a well water sample with the NIST thermometer and comparing that to the logger reading. Due to the constraints of measurement the temperatures checks will not provide assurance of accuracy within the specifications of the thermistor.

Data Handling Quality Assurance

The Service made check discharge measurements by either using the wading measurement technique with a Price AA, or SonTek FlowTracker, or by using boat methods with an ADCP. Wading measurements followed the United States Geological Survey' (USGS) midsection method (Rantz et al. 1982). Records for these monitoring sites were worked following the standard procedures established by the USGS (Rantz et al. 1982). Raw data and worked records were stored in the WISKI database at the USFWS Water Resources Branch Office in Portland, OR.

RESULTS

Historical Channel and Hatchery Channel

Historical Channel at Structure 2

Flows from Icicle Creek at Structure 2 are shown in figure 6. Flows calculated over 1680 cfs were considered estimated due to the lack of available check flow measurements to corroborate high flows. These flows occurred from January 16, 2011 to January 18, 2011 and intermittently between May 15, 2011 and June 30, 2011. Data is also estimated during freezing temperatures when ice was present in the stilling well. Freezing temperatures occurred between November 22 and November 29, 2010 and between December 30, 2010 and January 14, 2011. The flows measured at the Icicle Creek above Snow Creek (USGS, 2011) were compared to the Icicle Creek near Leavenworth (Ecology, 2011) (figure 7). The Icicle Creek above Snow Creek site is located just upstream of the Snow Creek input to Icicle Creek and the Icicle Creek near Leavenworth site is located one-half mile downstream of the last of LNFH operations. The shape of the hydrograph of Hatchery Channel at Structure 2 site follows the shape of the hydrographs from the Icicle Creek above Snow Creek and Icicle Creek near Leavenworth stream gaging sites.

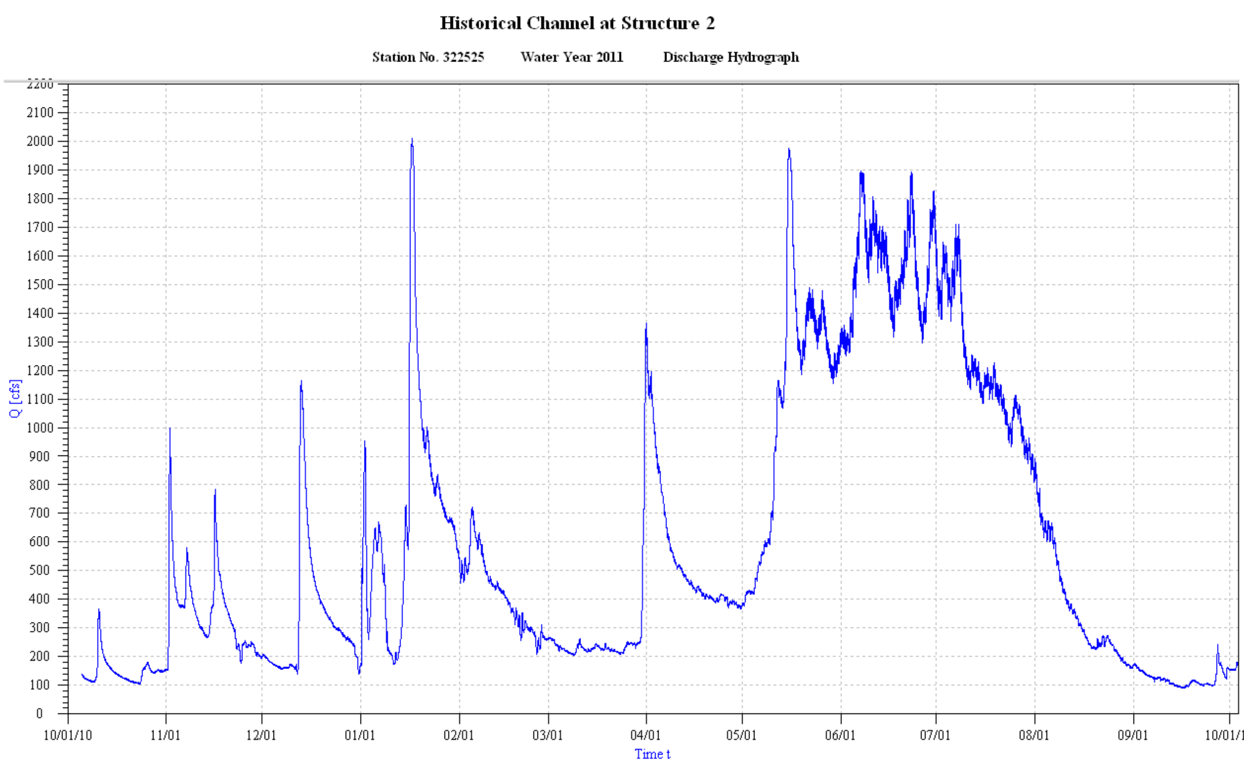

Figure 6. Hydrograph of discharge (Q) in cfs through Historical Channel at Structure 2 (322525) for Water Year 2011.

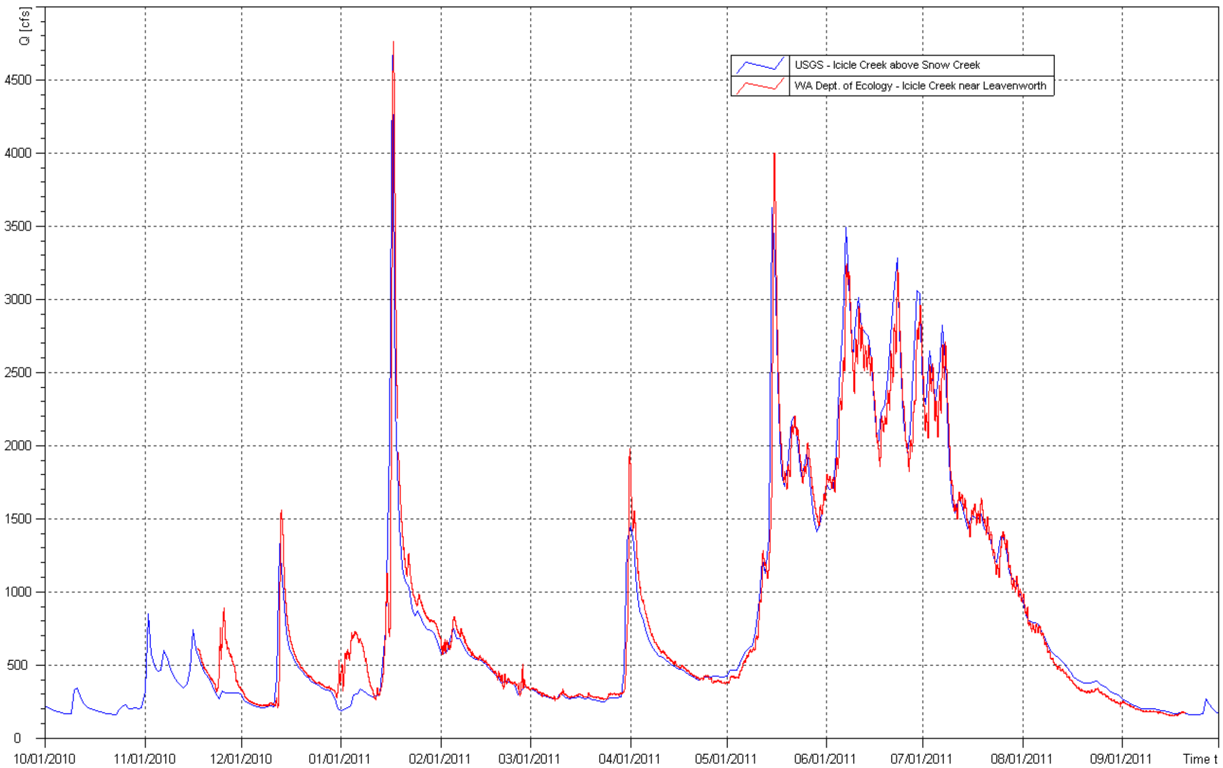

Figure 7. Hydrograph of discharge (cfs) measured at the USGS site – Icicle Creek above Snow Creek (in blue) and the Washington Department of Ecology site – Icicle Creek near Leavenworth (in red) for water year 2011.

Hatchery Channel at Spillway

Flows at the Hatchery Channel at Spillway site are shown in figure 8. Continuous recorded data began on May 10, 2011. Flows over the spillway began on May 11, 2011 and continued until July 30, 2011. Water remained pooled in the channel until August 15, 2011 when the bubbler and datalogger were turned off because the hatchery channel was dry. Data collected at the channel at spillway site is considered estimated due to inability to reference recorded data to the staff plate when water levels were too high to access the staff plate or when water levels were beneath the lowest measurement point of the staff plate. The recording equipment was referenced to the staff plate when water first crested the weir on May 11, 2011.

Water levels and discharge can be compared between the Historical Channel at Structure 2 site and the Hatchery Channel at Spillway site (figures 9 and 10). Understanding the correlation between the two sites is particularly helpful for LNFH to make management decisions. In figure 6, water levels of 2.30 feet (312 cfs) measured with the wire-weight gage at the Historical Channel at Structure 2 site occurs when the lowest water levels pool at the Hatchery Channel at Spillway site. At water levels of 2.99 feet at the Hatchery Channel at Spillway site, water levels of 4.64 feet and 890 cfs of flow occur at the structure 2 site.

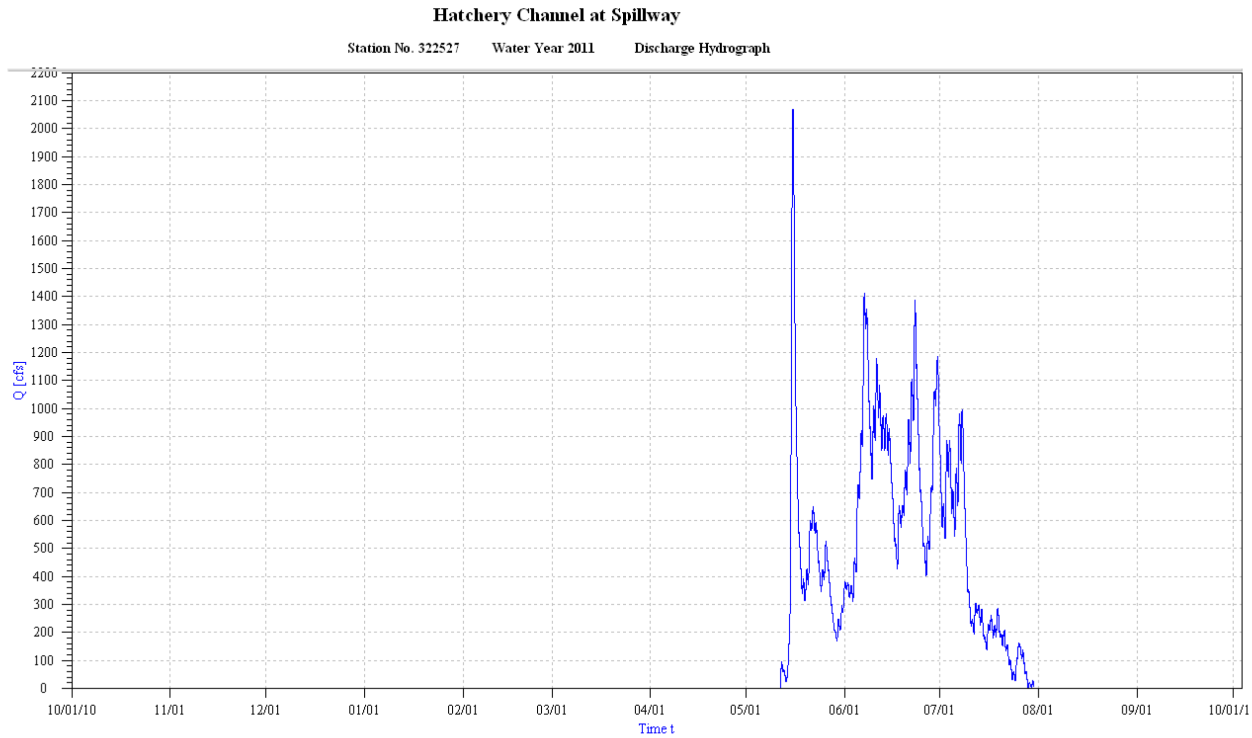

Figure 8. Hydrograph of discharge through the Hatchery Channel at Spillway site (322527) for Water Year 2011.

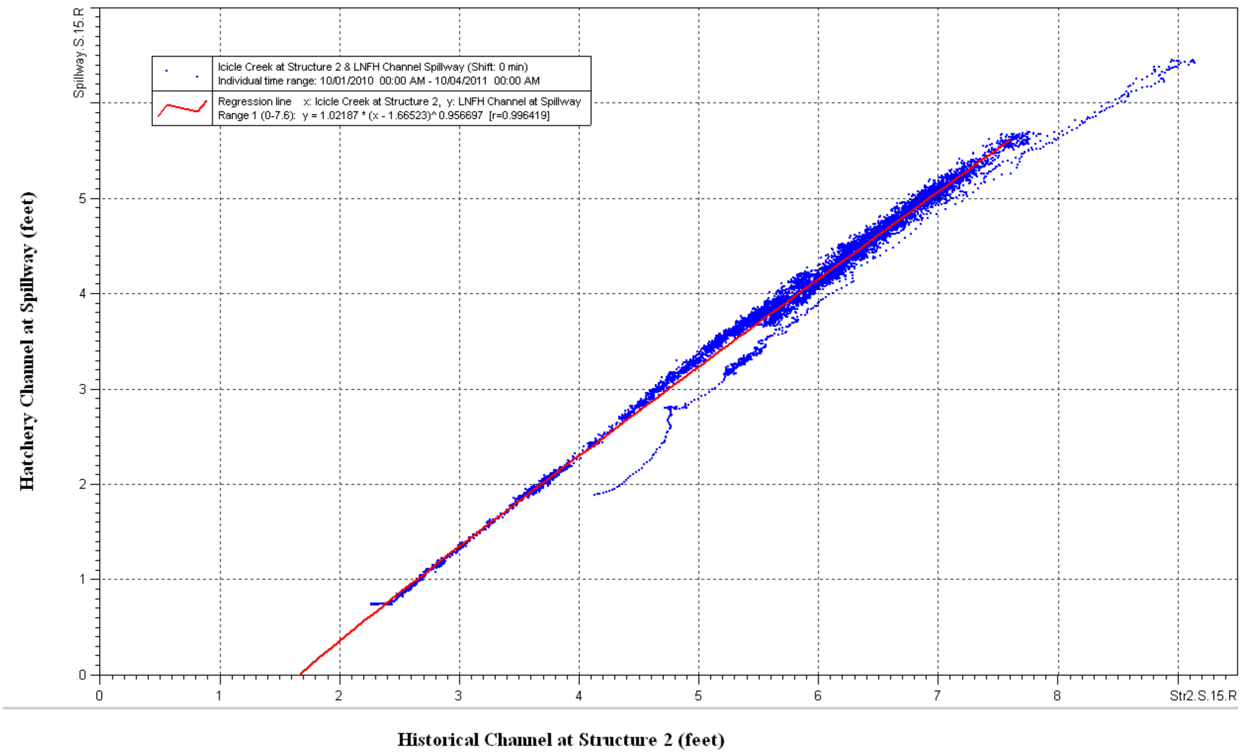

Figure 9. An x-y and regression plot of stage values (feet) for Historical Channel at Structure 2 and Hatchery Channel at Spillway in blue dots and regression line in red.

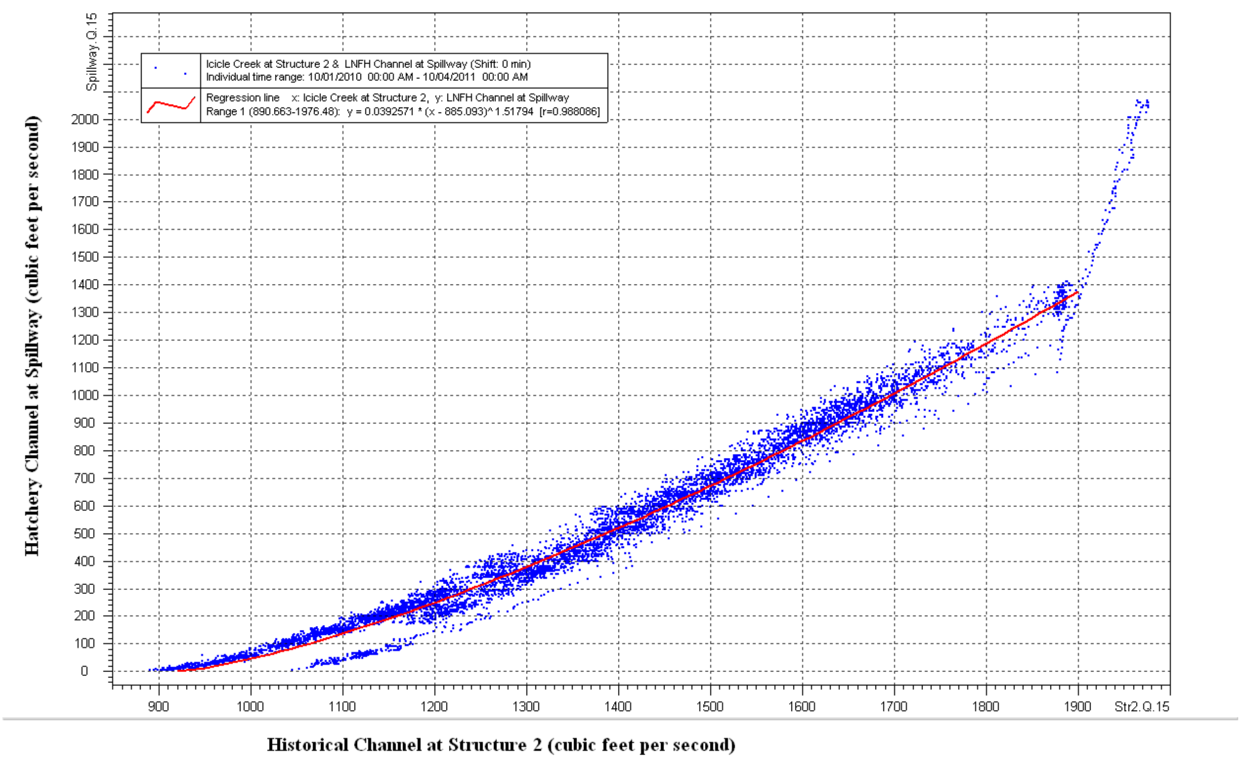

Figure 10. An x-y and regression plot of discharge values (cfs) for Historical Channel at Structure 2 and Hatchery Channel at Spillway site in blue dots and regression line in red.

Snow Lakes and Snow Creek

Snow Lake Outlet

Discharge (cfs) released from the outlet pipe and total storage (ac-feet) from the Snow Lakes Outlet site are shown in figures 11 and 12. The outlet valve was opened 22 degrees on August 3, 2011 (Table 4). Three subsequent valve changes occurred before the outlet valve was closed for the winter on October 3, 2011. Total storage for Snow Lakes increased from 7050 ac-feet on October 3, 2010 to 12,436 ac-feet on August 3, 2011. Storage dropped to 8,399 ac-feet by the time the valve was closed on October 3, 2011. The difference of 4740 ac-feet between these two points represents the total volume released for the season.

Table 4. Snow Lakes Outlet valve adjustments.

Date	Valve Adjustment
08/03/2011	22 degrees
08/12/2011	30 degrees
08/18/2011	35 degrees
08/31/2011	47 degrees
10/03/2011	0 degrees

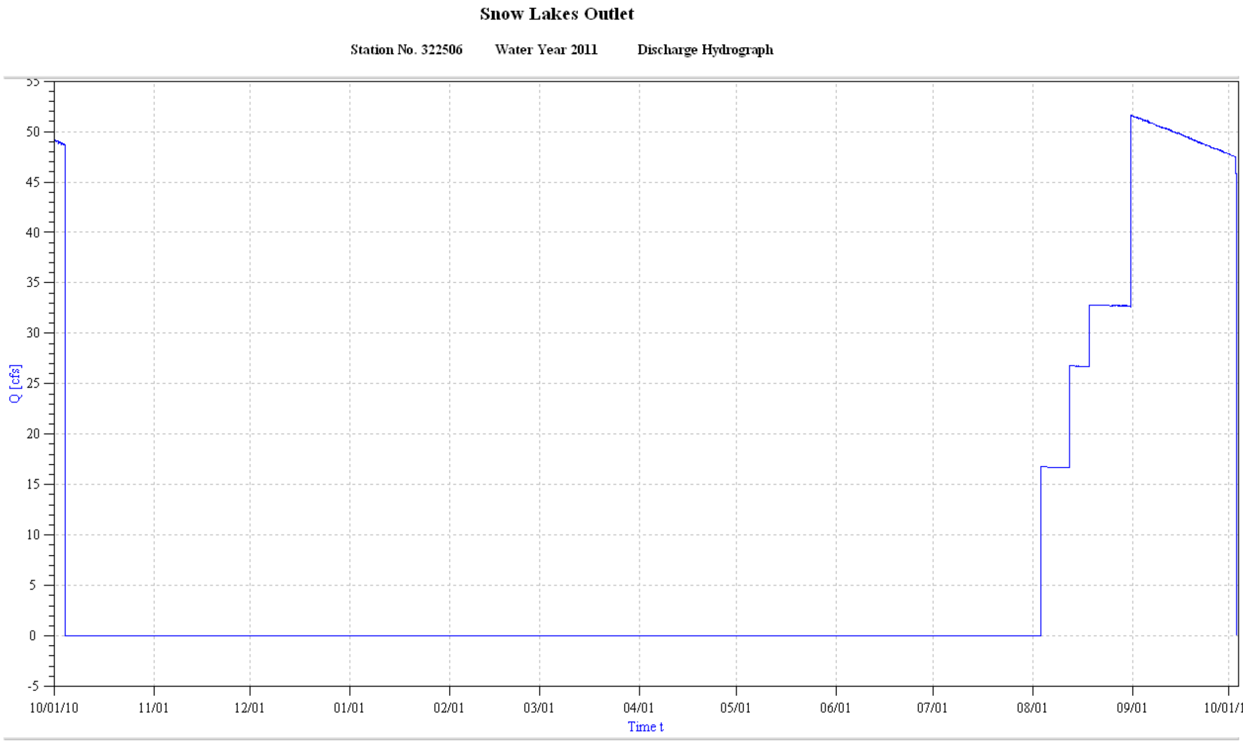

Figure 11. Hydrograph of discharge through the valve at the Snow Lakes Outlet (322506) for Water Year 2011.

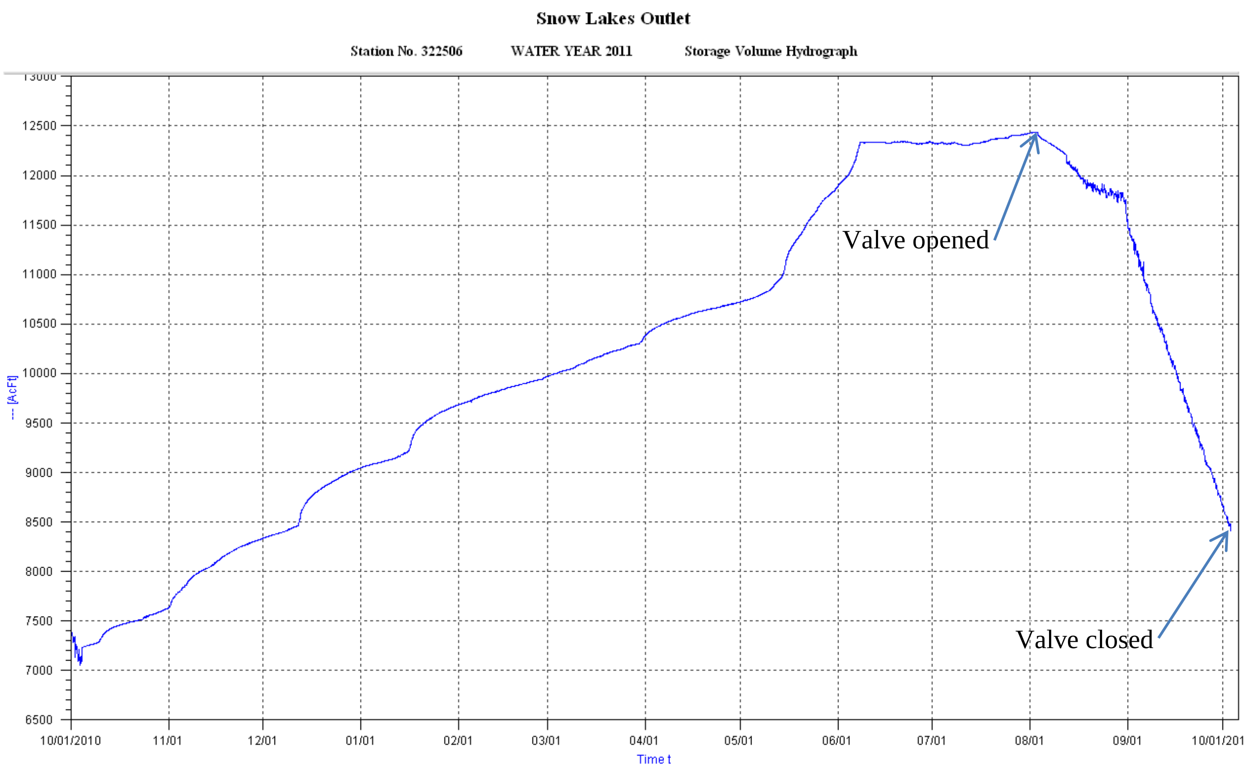

Figure 12. Hydrograph of volume storage in the Snow Lakes Outlet site (322506) for Water Year 2011.

Snow Creek Mouth

A discharge hydrograph for the Snow Creek Mouth site is shown in figure 13. The timing of peaks in Snow Creek is similar to the timing of peaks measured on Icicle Creek. Discharge increases at Snow Creek Mouth after August 5 was related to releases for Snow Lake. The Snow Creek hydrograph shows a late summer increase in response to releases from Snow Lake rather than a typical late summer streamflow decrease (figure 14).

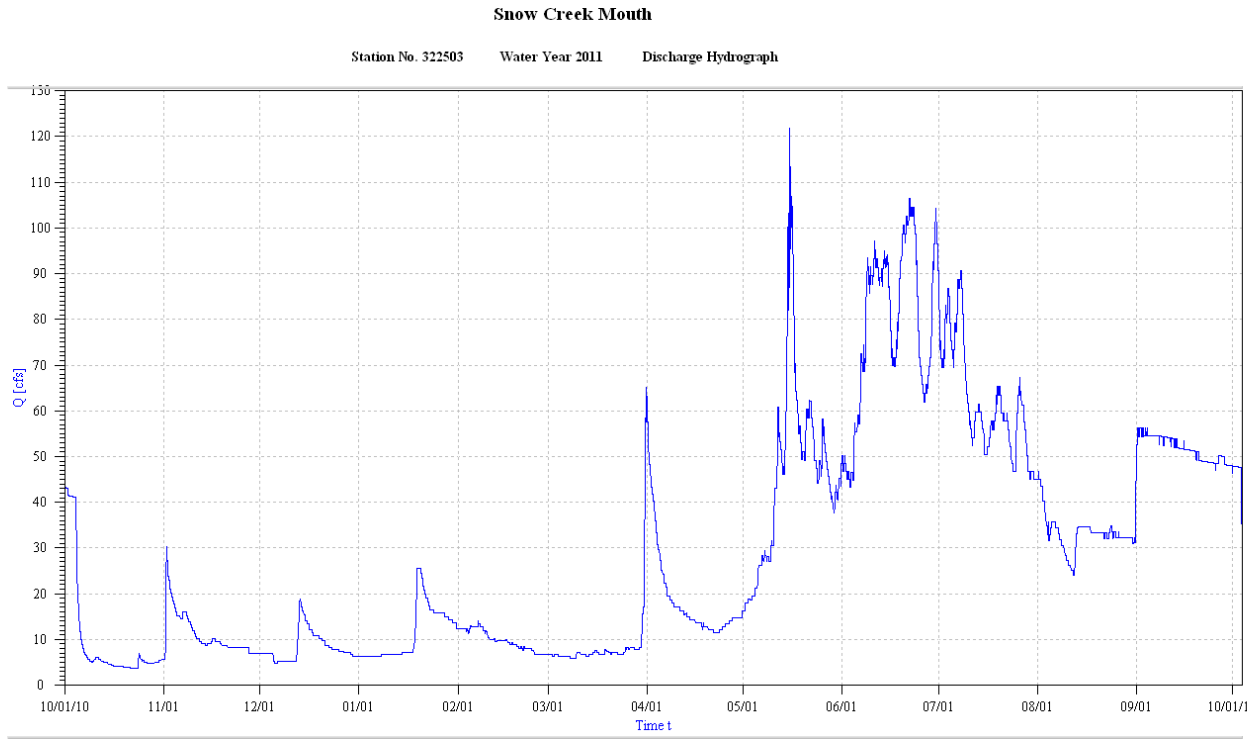

Figure 13. Hydrograph of discharge at the Snow Creek Mouth site (322503) for Water Year 2011.

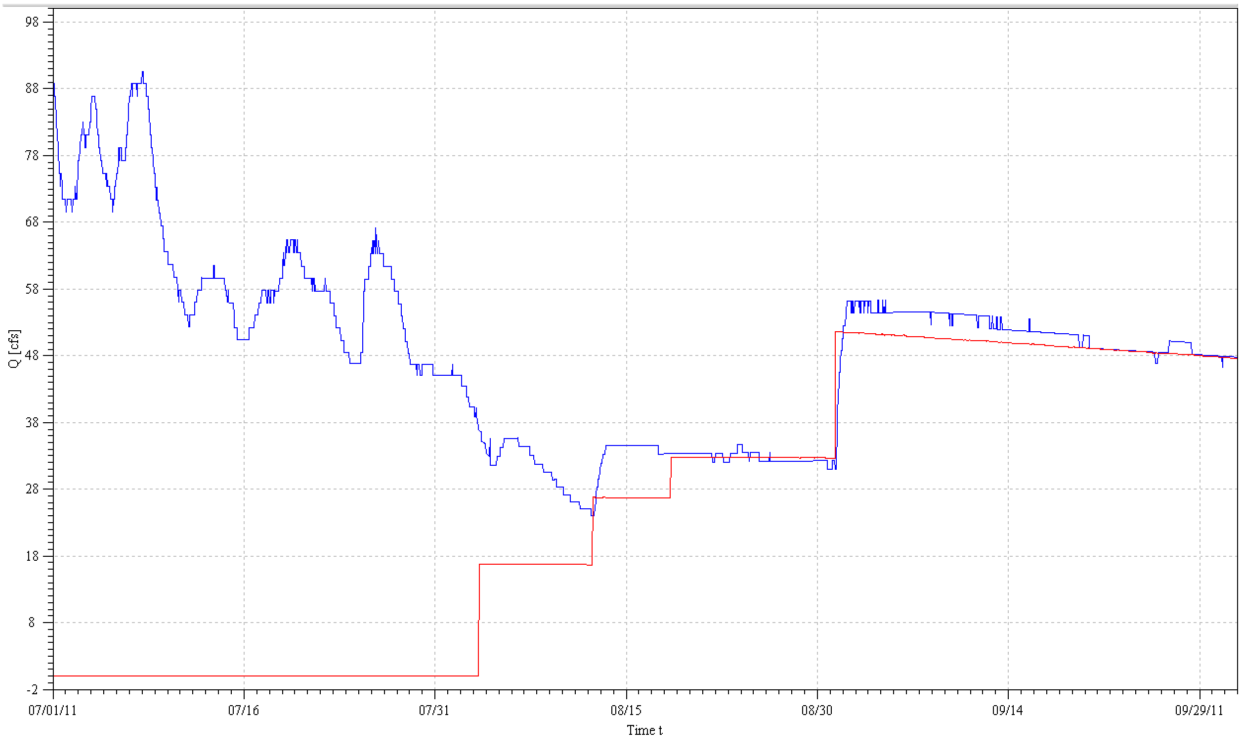

Figure 14. Hydrograph of continuous discharge (cfs) in the Snow Lakes Outlet site (322506) shown in the red line and discharge (cfs) in the Snow Creek Mouth site (322503) shown in blue line between 07/01/2011 and 10/01/2011.

Inflows and Outflows from the LNFH

LNFH Icicle Creek Diversion

A discharge hydrograph of the LNFH Icicle Creek Diversion site are shown in figure 14. Acquiring quality data was problematic due to high flows and rapidly changing sediment height and area profiles in the diversion channel. Starting May 15 and continuing through June, flows increased in the Diversion Channel as flows increased in Icicle Creek. It is likely that the water returned to Icicle Creek instead of the LNFH, either through the overflow spill section in the small building downstream of the diversion intake canal or water overflows the banks of the diversion canal after downstream of the point of measurement. The ADVM was buried by sediment on June 22, and was dug out and repositioned higher in the channel on July 19. During this time period, the infill of sediment caused higher velocities and lower area profiles, resulting in overestimated flows. To account for this, the velocity was shifted up and the area profile was shifted down. It is likely the sediments originated from a landslide that occurred upstream of the diversion channel. Higher velocities transported the landslide sediment load, which was deposited in the diversion channel between May 15 and the end of July. Subsequently, the sediments were transported out of the diversion channel during the summer months, requiring constant channel profile changes to area profile geometries and adjustments to the height of the ADVM in the water column. As a result, much of the area data was shifted between July 21 and October 1, 2011. By the end of the water year, the channel profile had returned to a geometry similar to that observed in the spring. Discharge calculated between April 5, 2011 and May 15, 2011 and between July 21 and October 1, 2011 is considered estimated. Discharge calculated between May 15, 2011 and June 22, 2011 is considered suspect.

Based on observations from LNFH personnel, changes in area profile geometry at the ADVM measurement point should not occur with such frequency and magnitude in most years. To capture changes in the area profile geometry that occur after high flows in Icicle Creek, site visits will increase to bi-weekly during the spring-summer snowmelt and immediately following short duration peak-flows.

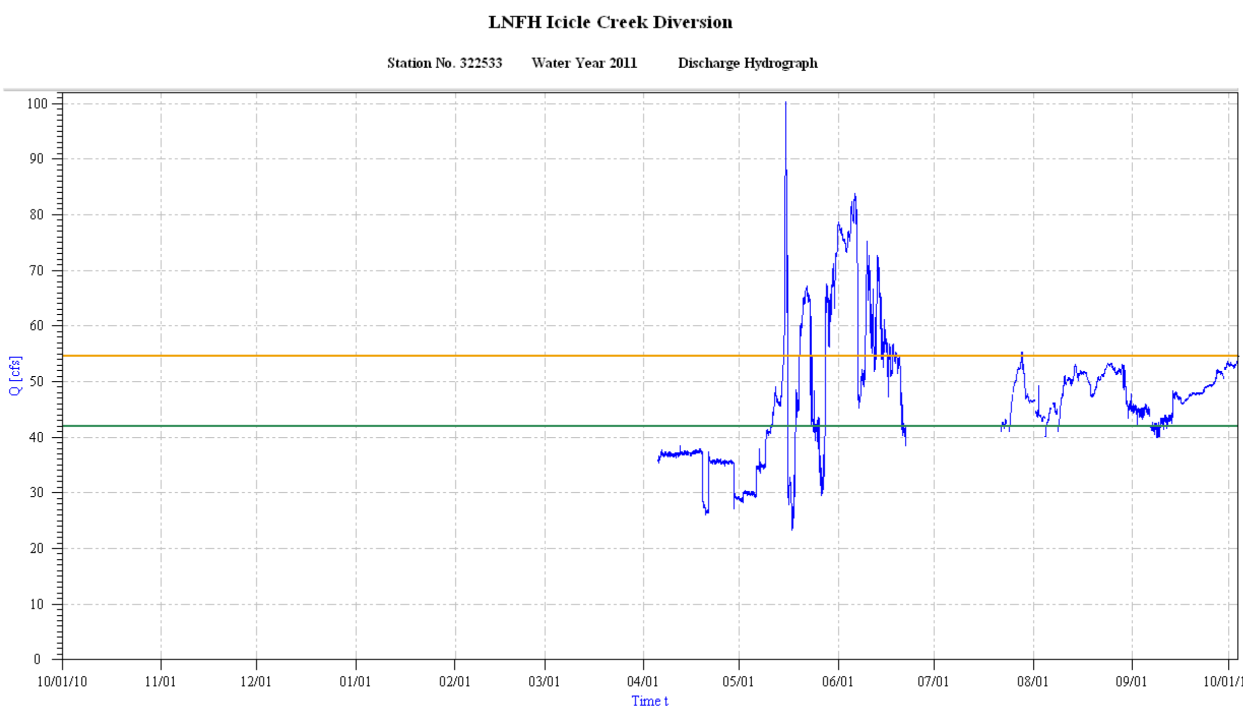

Figure 15. A hydrograph of flows through the LNFH Icicle Creek Diversion for Water Year 2011. The green line denotes the amount of flow for LNFH water rights and the orange line denotes the amount of flow for COID water rights and addition to LNFH water rights.

Production Wells 1-7

Production well discharge is shown in figure 16 and 17. The sum of the total hourly well discharge is included in the hydrograph, with the scale on the furthest left y-axis.

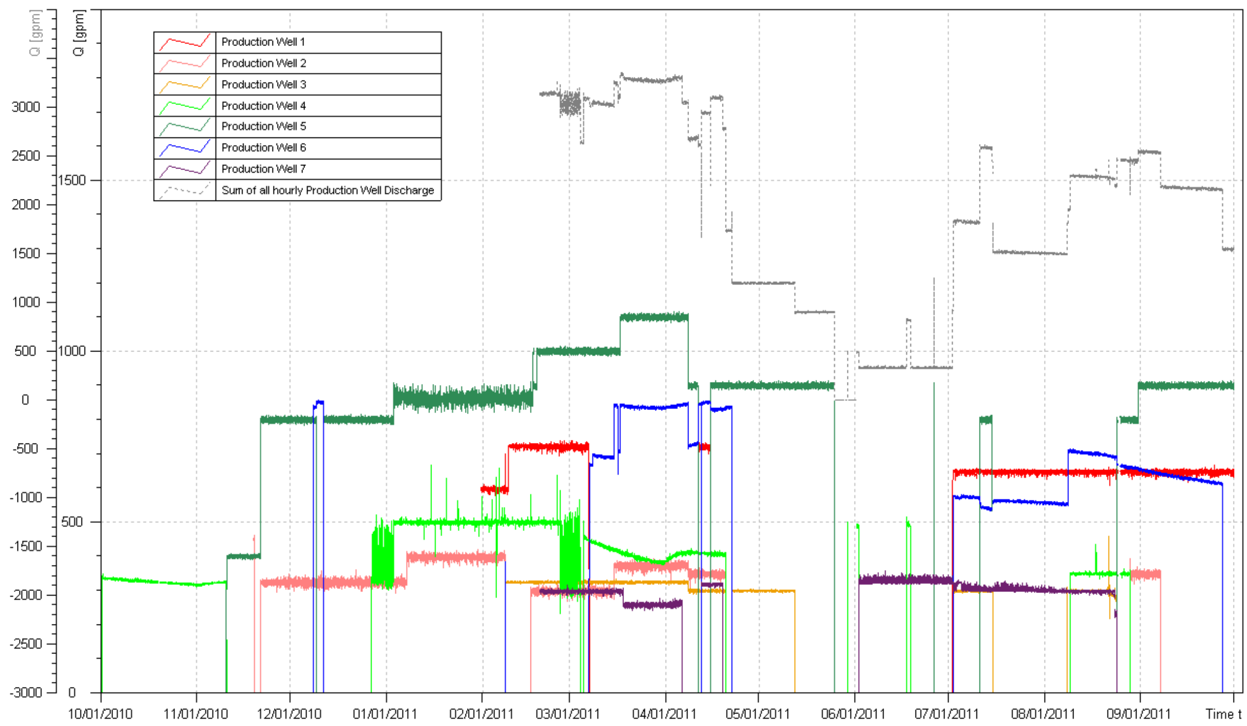

Figure 16. Hydrographs of well discharge (gpm) of Production Well: PW-1 (red), PW-2 (pink), PW-3 (orange), PW-4 (light green), PW-5 (dark green), PW-6 (dark blue), PW-7 (purple), and the sum of all hourly Production Well Discharge (grey) for Water Year 2011. The y-axis scale for Sum of all hourly Production Well Discharge is in grey and the y-axis scale for the individual Production Wells is in black.

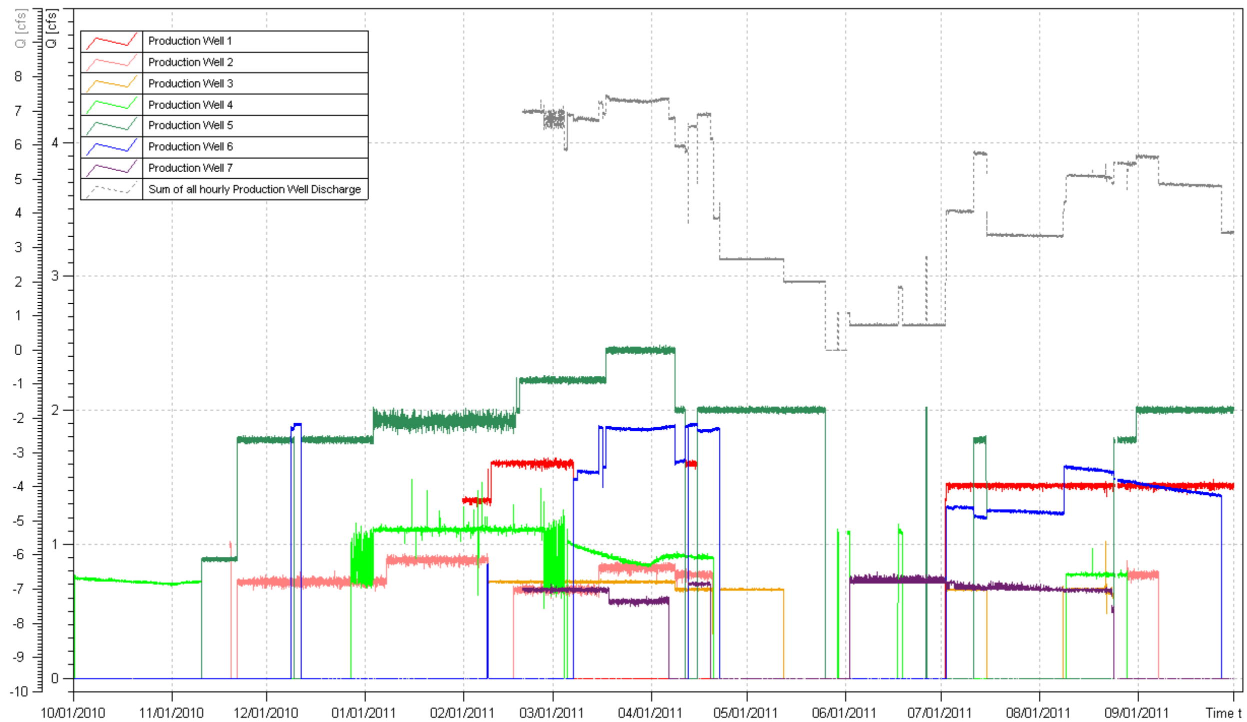

Figure 17. Hydrographs of well discharge (cfs) of Production Well: PW-1 (red), PW-2 (pink), PW-3 (orange), PW-4 (light green), PW-5 (dark green), PW-6 (dark blue), PW-7 (purple), and the sum of all hourly Production Well Discharge (grey) for Water Year 2011. The y-axis scale for Sum of all hourly Production Well Discharge is in grey and the y-axis scale for the individual Production Wells is in black.

LNFH Discharge at Fish Ladder (Outfall 1)

Discharge calculated out of the fish ladder (Outfall 1) is consistent throughout the year, ranging between 35 and 50 cfs (figure 18). Flows above 55 cfs are likely too high and are caused by submergence of the flume when flows in Icicle Creek exceed 1400cfs. Submergence occurred on March 17 -21, April 27 – May 5, and May 15 – July 12.

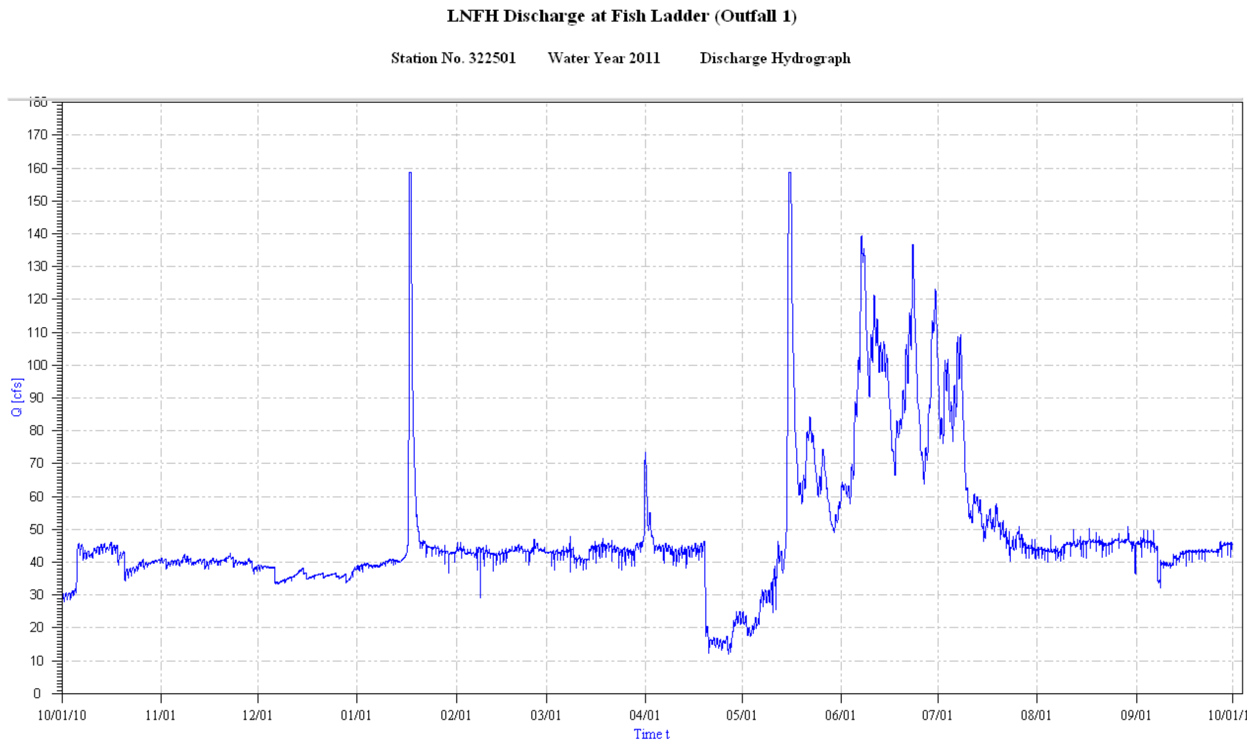

Figure 18. Hydrograph of discharge at the LNFH Discharge at Fish Ladder (Outfall 1) site (322501) for Water Year 2011.

LNFH Discharge at Abatement Pond (Outfall 2)

Discharge out of the LNFH Abatement Pond ranges between 0 and 6 cfs (figure 19) between July 21, 2011 when the recording equipment was installed and October 1, 2011. Flows calculated above 6 cfs are considered estimated because they exceed the height of the v-notch weir (1.5 feet).

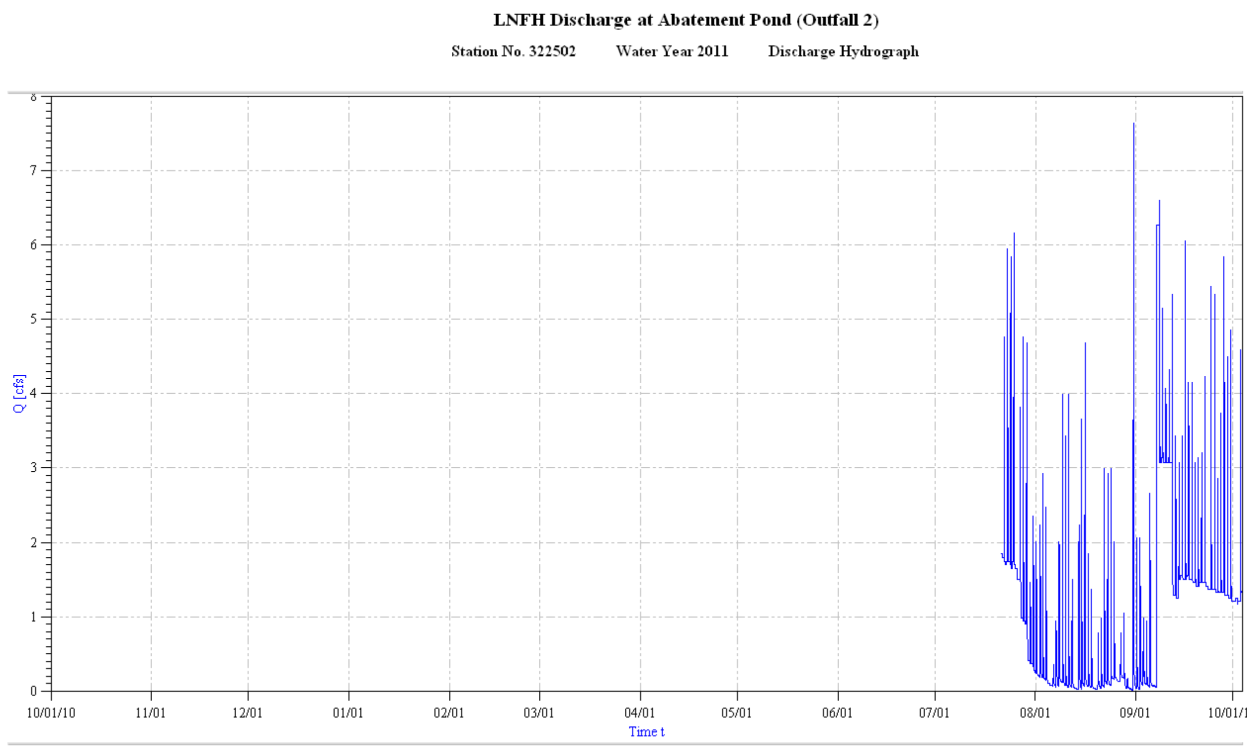

Figure 19. Hydrograph of discharge at the LNFH Discharge at Abatement Pond (Outfall 2) site (322502) for Water Year 2011

Discharge and Flow-Average Temperature Comparison

A comparison of hourly inflows and outflows into the LNFH are shown in figure 20. Inflows into the LNFH include discharge from the LNFH Icicle Creek Diversion and the Production Wells. Outflows of the LNFH include the LNFH Discharge at Fish Ladder (Outfall 1) and the LNFH Discharge at Abatement Pond (Outfall 2). Ideally, the Inflows minus Outflows hydrograph would result in a difference of 0 cfs. The difference shown on the graph is greater than zero most of the time and is attributable to unknown diversions of water in the pipeline between LNFH Icicle Creek Diversion and the LNFH. The Inflow minus Outflows hydrograph is not calculated for dates earlier than July 21 because there was no monitoring equipment at the LNFH Discharge at Abatement Pond prior to this date. The Inflows minus Outflows w/o Outfall 2 hydrograph does not include the outflow at LNFH Discharge at the Abatement Pond and is provided to view the inflow/outflow comparison for a longer period of time. Because this discharge is relatively small, its omission should matter little in the overall calculation of net inflow. Between April 4 and April 23 inflow minus outflow track very close to 0 cfs and are representative of actual flows into and out of the LNFH. Starting on April 23, 2011, flows are much higher at the LNFH Icicle Creek Diversion than at the LNFH Discharge at Fish Ladder. The discrepancy is likely due to an increase in diversion through the overflow spill section downstream of the diversion canal ADVM. As expected, there are large discrepancies between May 15, 2011 and June 22, 2011 when both the LNFH Icicle Diversion Intake and the LNFH Discharge at Fish Ladder sites were subject to inaccurate calculations of discharge due to high Icicle Creek flows.

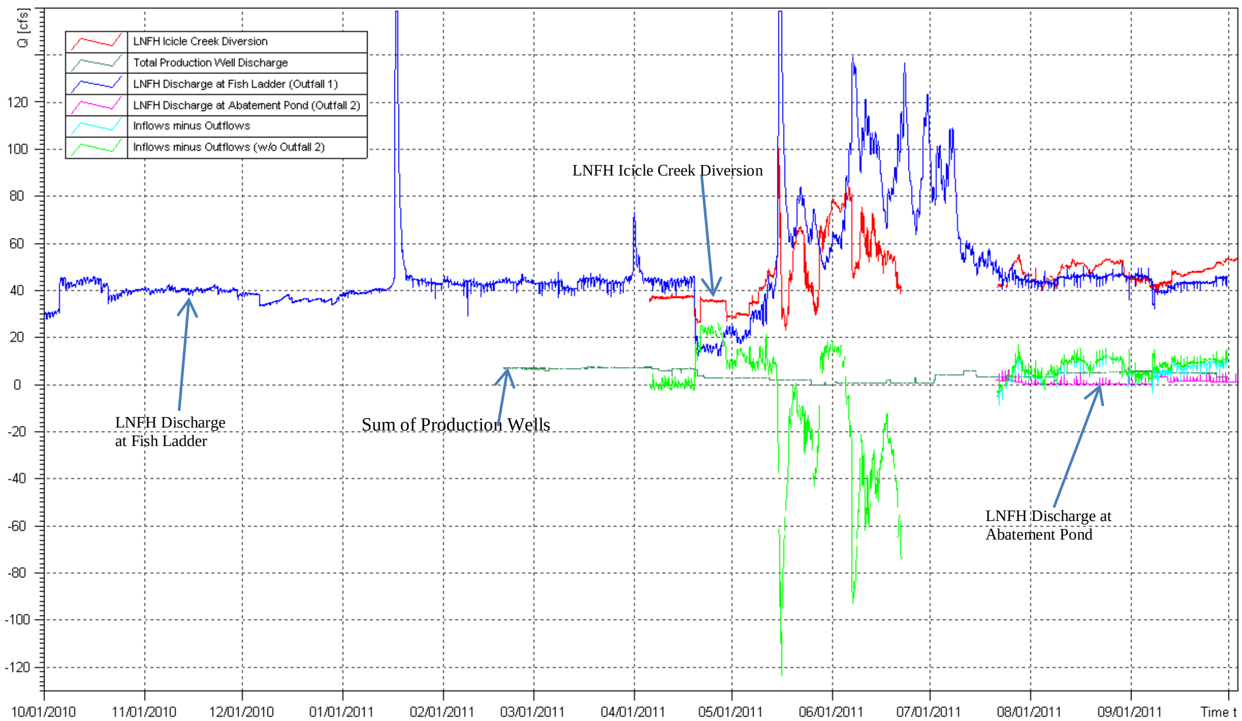

Figure 20. Discharge hydrographs (cfs) for hourly interval for the LNFH Diverstion Intake (red line), LNFH Discharge at Fish Ladder (Outfall 1) (blue line), LNFH Discharge at Abatement Pond (Outfall 2) (magenta line), Total Production Well Discharge (dark green line), Inflows minus Outlflows (without Outfall 2) (light green line), and Inflows minus Outflows (cyan line).

Inflow and outflow temperatures are shown in figure 21. Water temperatures measured in the production wells range between 40 and 55 degrees F and were higher than temperatures measured at the surface water inflow and outflow sites during winter months. Water temperatures measured at the LNFH Discharge at Abatement Pond was higher and more variable than temperatures measured at the LNFH Icicle Creek Diversion and LNFH Discharge at Fish Ladder during the summer months. This difference is due to the inherent design of the pollution abatement pond which exposes LNFH effluent to air temperatures and solar radiation over a large surface area. Discharge from the LNFH Discharge at Abatement Pond is very small relative to the flows in Icicle Creek and should not be significant in affecting Icicle Creek temperatures.

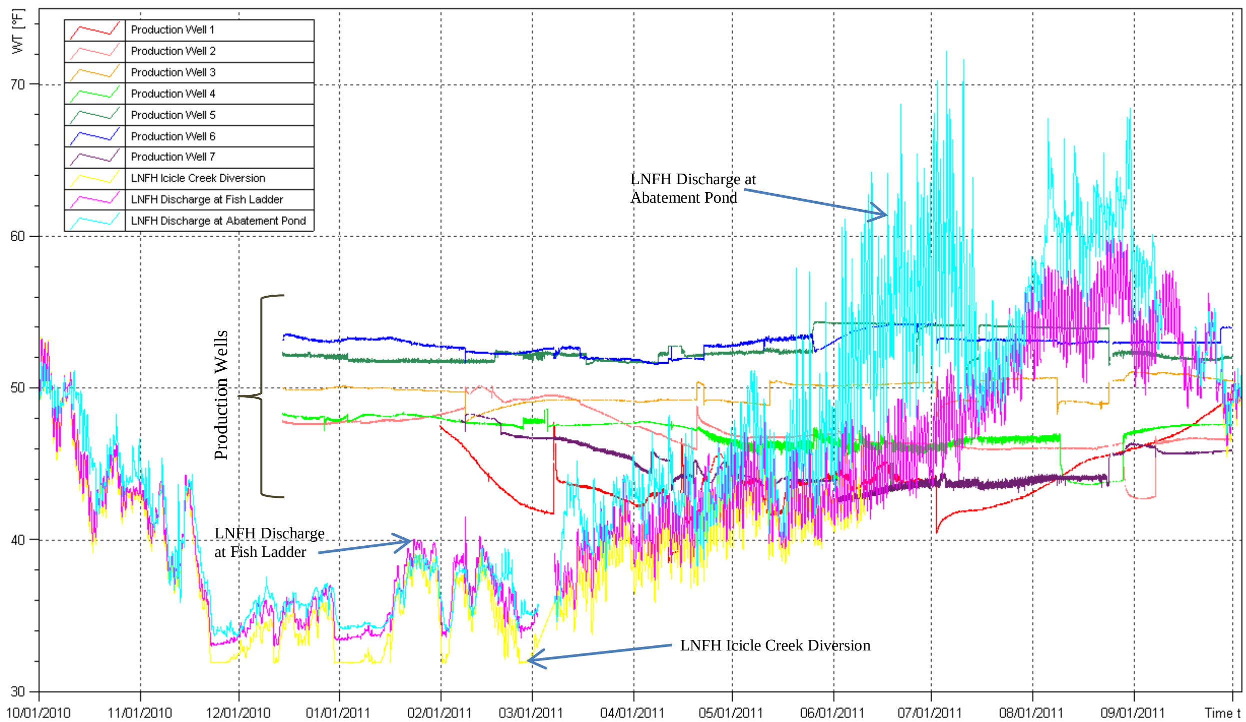

Figure 21. Hourly water temperature (degrees F) for LNFH Discharge at Abatement Pond (cyan), LNFH Discharge at Fish Ladder (magenta), LNFH Icicle Creek Diversion (yellow), Production Wells; 1 (red), 2 (pink), 3 (orange), 4 (light green), 5 (dark green), 6 (dark blue), and 7 (purple).

Flow-averaged temperature is calculated using a technique that assumes temperature is a conservative tracer and there is no loss or gain of mass. The equation to calculate flow averaged-temperature is shown in equation 5.

Equation 5.

averaged temperature and suggests that there is a slight increase in water temperature through the LNFH. Flow-averaged temperature ranges between 0 and 15 degrees Fahrenheit less than the LNFH Discharge at Abatement Pond site (light green line). The difference between the calculated flow-averaged temperature and the temperatures of the LNFH Discharge at Abatement Pond indicate that LNFH operations and the Pollution Abatement Pond increases the temperature of water released to Icicle Creek.

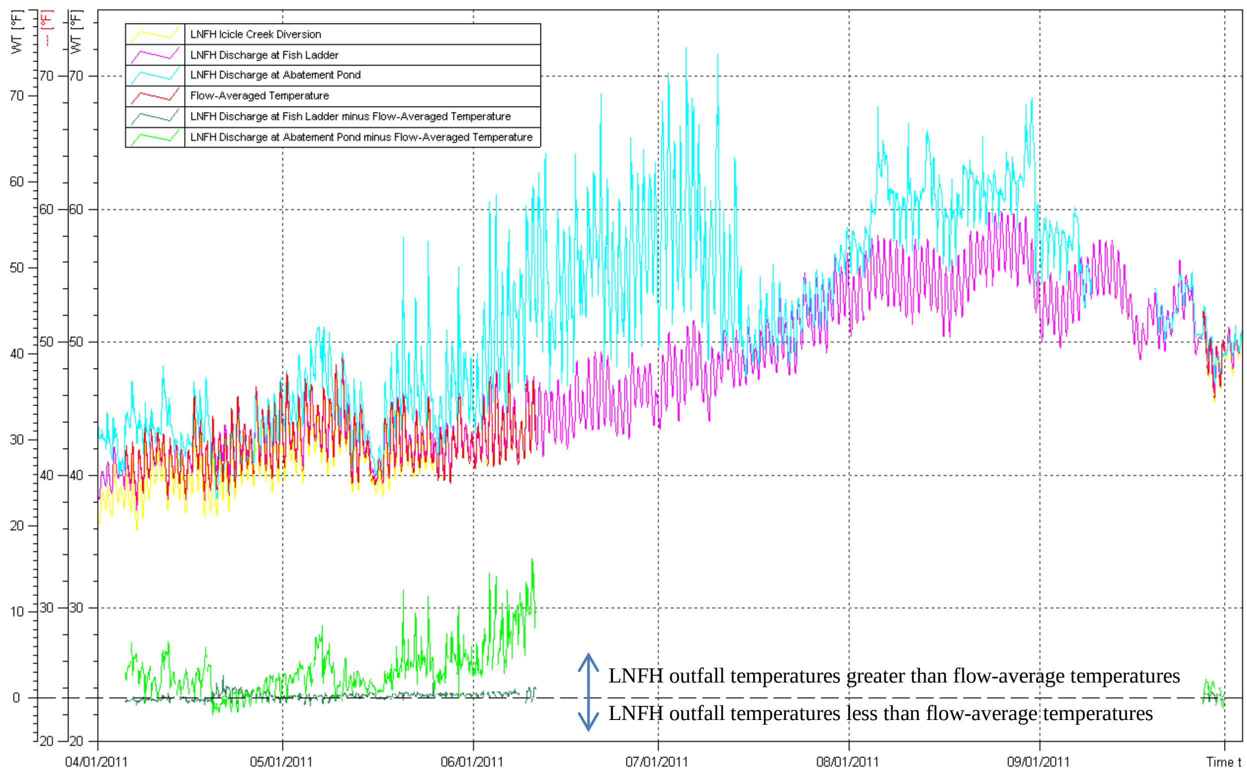

Figure 22. Hourly water temperature (degrees F) for LNFH Discharge at Abatement Pond (cyan), LNFH Discharge at Fish Ladder (magenta), LNFH Icicle Creek Diversion (yellow), flow-averaged temperature (red), the difference between LNFH Discharge at Fish Ladder and flow-averaged temperature (dark green), and the difference between LNFH Discharge at Abatement Pond and flow-averaged temperature (light green).

Water returned to Icicle Creek from the LNFH will influence the temperature of Icicle Creek based on the amount and the temperature of the Outfall and of Icicle Creek. To determine the potential influence of LNFH Outfall temperatures on Icicle Creek temperatures, the flow-average temperature technique was applied to the mixing of LNFH Discharge at Fish Ladder or the LNFH Discharge at Abatement Pond with Icicle Creek. The temperature and discharge data to represent Icicle Creek was obtained from the site one-half mile downstream of the LNFH at the WA Dept of Leavenworth – Icicle Creek near Leavenworth site. Flow-average temperature of LNFH Discharge at Fish Ladder and Icicle Creek is shown in Figure 23. Flow-averaged temperature tends to be similar to temperature measured at the Icicle Creek near Leavenworth site and cooler than LNFH Discharge at Fish Ladder. The difference between the flow-average temperature and the temperatures of the Icicle Creek near Leavenworth site (dark green) indicate that generally the outfall at LNFH Discharge at Fish Ladder will either increase or decrease the temperature of Icicle Creek by a few tenths of a degree Fahrenheit. In August and September, flow-averaged temperature was cooler than the Icicle Creek near Leavenworth site, which suggests that the flow out of the LNFH Discharge at Fish Ladder cooled Icicle Creek. Flow-average temperature of LNFH Discharge at Abatement Pond and Icicle Creek is shown in Figure 24. Flow-averaged temperature was more similar to temperature measured at the Icicle Creek near Leavenworth site. The difference between the flow-average temperature and the temperatures of the Icicle Creek near Leavenworth site (dark green) indicate that generally the outfall from the LNFH Discharge at Abatement Pond increases or decreases the temperature of Icicle Creek by a few hundredths of a degree Fahrenheit and occasionally by a few tenths of a degree Fahrenheit. The specifications of error for most temperature thermistors are within +/- 0.36 degrees Fahrenheit. Therefore, the differences of flow-averaged temperatures and the temperatures measured at the Icicle Creek near Leavenworth site of less than +/- 0.36 degrees Fahrenheit can be attributed to the error associated with measurement.

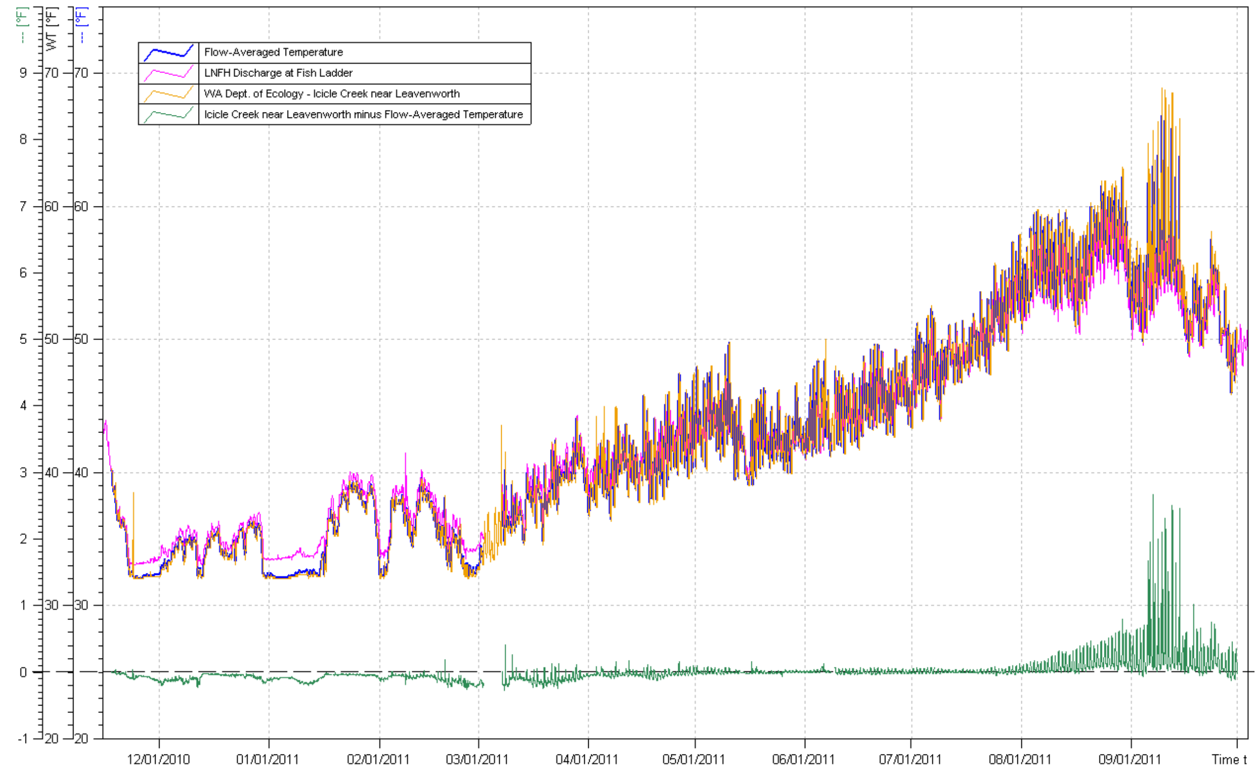

Figure 23. Hourly water temperature (degrees F) for LNFH Discharge at Fish Ladder (magenta), WA Dept of Ecology – Icicle Creek near Leavenworth site (yellow), flow-averaged temperature (blue), the difference between WA Dept of Ecology - Icicle Creek near Leavenworth site and flow-averaged temperature (dark green).

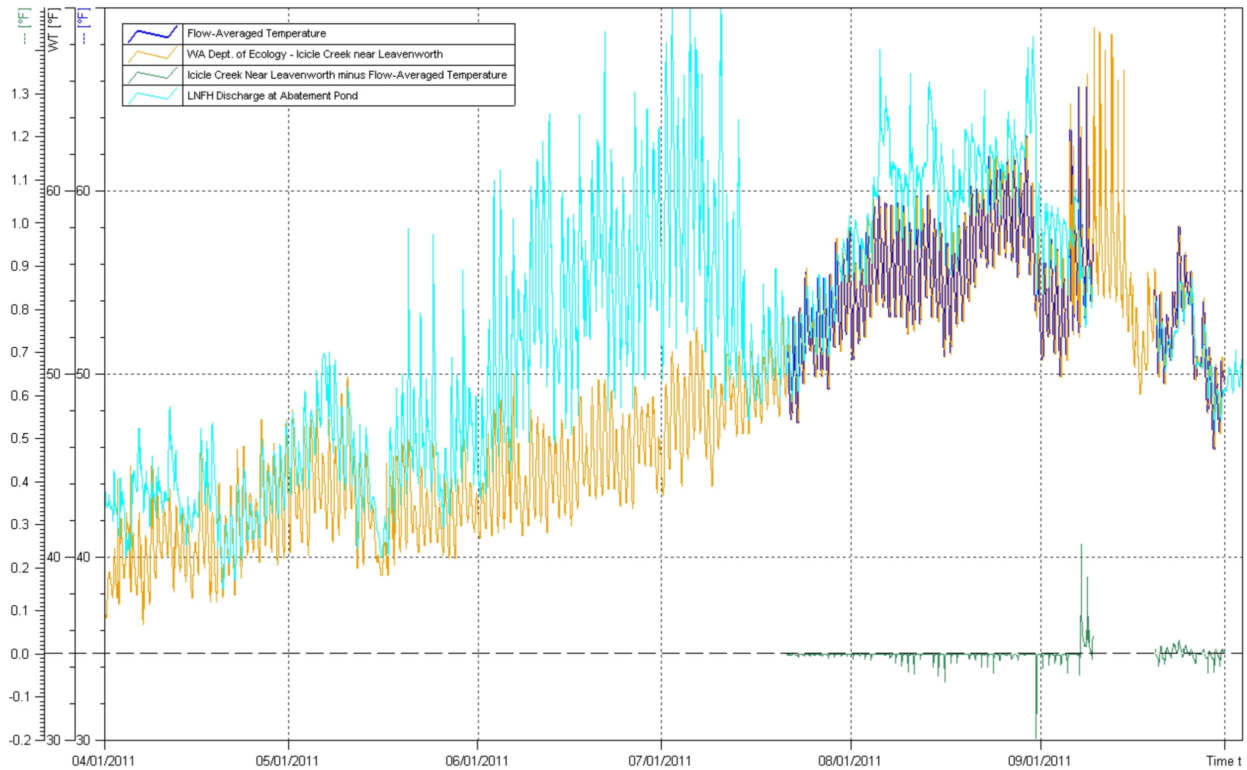

Figure 24. Hourly water temperature (degrees F) for LNFH Discharge at Abatement Pond (cyan), WA Dept of Ecology – Icicle Creek near Leavenworth site (yellow), flow-averaged temperature (blue), the difference between WA Dept of Ecology - Icicle Creek near Leavenworth site and flow-averaged temperature (dark green).

SUMMARY

Changes in discharge measured at Icicle Creek at Structure 2 and LNFH Channel at Spillway sites correspond with the discharge measured at the USGS and Ecology stream gaging sites on Icicle Creek. The lowest flows over the LNFH Channel at Spillway correspond with 890 cfs at the Icicle Creek at Structure 2 site. Discharge out of the Snow Lakes Outlet site started on August 3, 2011. These flows out of the Snow Lakes are present at the Snow Creek Mouth site. Production Wells combined discharge adds approximately 5 to 10 cfs of inflow to the LNFH. LNFH Icicle Creek Diversion and LNFH Discharge at Fish Ladder sites require further investigation to obtain quality assurance of data. For example, to determine the quantity of flow to the LNFH after measurement at the LNFH Icicle Creek Diversion site the water returning to Icicle Creek through the overflow spillway at the intake house and diversions to COID will need to be measured. Assuring accuracy of flow measurements out of the LNFH Discharge at Fish Ladder site will require determining submerged flume water depths as well as the ability to check water depths in flume and stilling well. The assurance of quality data from Snow Lakes Outlet and Snow Creek

Mouth will continue with investigations into flow measured at the Nada Lake site. Flow-averaged temperature analysis shows that operations at the LNFH do increase and decrease temperatures of the water used by the LNFH. By using the same flow-averaging temperature analysis to determine the LNFH temperature influence on Icicle Creek, evidence suggests that the releases from the LNFH have minimal influence on the temperatures of Icicle Creek. With the measurement sites fully functional throughout water year 2012 the next annual report will provide a more robust data set of discharge and temperature analysis.

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